University of Alberta

Anthropogenic Soils at Two Norse Farms in Greenland and Iceland

by

Courtney Cameron ©

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ABSTRACT

The Norse disappeared from Greenland around A.D. 1500. Many theories have been developed to explain this disappearance; including one in which poor soil management leads to the downfall of Norse agriculture. Infield pastures were integral components of Norse farms as they were used for growing fodder that sustained the livestock through winter. Therefore infield soil quality is important in sustaining Norse farms.

Infield soil was collected from two Norse sites (GUS in Greenland and Háls in Iceland) and was chemically analyzed. The purpose of the analysis was to determine whether the infield soil quality was enhanced, maintained, or depleted during the period of occupation.

Results from the samples collected from GUS indicate that infield soil quality increased during Norse Occupation. The stable isotope results indicate that soil quality was maintained primarily by animal manure that was unevenly distributed across the infield. Therefore soil exhaustion at GUS was not the reason for site abandonment.

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CHAPTER 1: INTRODUCTION

The circumstances surrounding the Norse disappearance from Greenland is the greatest mystery in Norse archaeology. Many theories have been advanced to account for this, one of which questions the ability of the Norse to maintain their subsistence strategy in a deteriorating climate. The object of the research presented in this thesis is to test the hypothesis that Norse agricultural practices positively affected the quality and productivity of their infield[1] soils throughout their occupation of Greenland and this helped to sustain their subsistence strategy in the "marginal" (Brasen 2001) environments of Greenland and Iceland. This hypothesis is tested through the chemical analysis of soil samples recovered from anthropogenic[2] soils from archaeological sites Gården Under Sandet (GUS), Western Settlement, Greenland, and Hálsaveit (Háls), Iceland.

Four research questions are pursued to test the sustainability of infield agriculture and Norse infield management.

1.Did the Norse affect the concentration of key chemical constituents of the infield soil?

2.And if so, how did the infield soil change during the time that the Norse occupied the farms at GUS and Háls?

---

1. The Norse divided their fields into infields and outfields. The former provided hay and the latter was used for grazing.

2. Anthropogenic soil is soil created by intentional or unintentional human activities (Waters 1992:32)

3. Was fertilizer distributed across the entire infield at GUS and Háls?

4. What was the origin of the fertilizer? Did the Norse at GUS and Háls strictly use animal manure, or did they use seaweed as a fertilizer?

The use of chemical analysis to test Schweger's hypothesis that the Norse farmers practiced sustainable farming (Schweger 2000) followed Zutter's (1997) observations from Iceland that if the Icelandic Norse actively maintained their infields through the introduction of fertilizers, there would be high concentrations of phosphates in their fields, pastures, and barnyards, and that these higher phosphate concentrations could still be evident and quantifiable in anthropogenic soils.

Three chemical methods of soil analysis are employed in this thesis; 1) phosphate analysis is used to measure the total levels of phosphate in the soil to help determine the possible level of human intervention (Zutter 1997); 2) cation exchange capacity (CEC) is used to measure the amount of cations that can be held in the soil, a determinant of soil productivity, and to show how the soil productivity changed over time; and 3) stable carbon and nitrogen isotopic analysis is used to identify potential sources of fertilizers that could have been applied to the soils.

In Greenland and Iceland, past research has focused on landscape changes brought about by the arrival of the Norse, most particularly to the vegetation, and in the erosional effects of past livestock overgrazing (Arnalds 1999; Fredskild 1992; Jackson 1970; Jacobsen 1987; Jakobsen 1991b, c). None of the research to this point has examined how the infield soils were changed over time due to Norse presence.

The Norse in Greenland migrated from Iceland and therefore shared a common culture with the Icelanders. Along with their animals and belongings, the Icelanders transported their economical, ideological, and technological knowledge to Greenland. As a result, both Norse populations shared similar agricultural strategies, and the implementation of these agricultural strategies would have created similar cultural landscapes.

The cultural landscape represents "… an artefact of a specific culture at a certain time, influenced by its social, economic, ideological and political spheres" (Zutter 1997). Zutter notes that the cultural landscape is created, maintained, and transported into new areas. Thus, soil from the infields of Norse Greenlandic and Norse Icelandic farms are artifacts, or parts of the cultural landscape. The cultural landscape forms the basis for the comparison of Norse farm sites in Greenland and Iceland.

Historically, the infield pastures of a Norse farm were utilized for growing the majority of the winter fodder for animals. This agricultural strategy resulted in the infield becoming an integral component of Norse animal husbandry. By determining if the infield soil quality was enhanced, maintained, depleted, or not affected by the Norse, the overall sustainability of the Norse farming methods can be determined.

For the GUS site in the Western Settlement in Greenland, the pre-settlement and anthropogenic soils are analyzed in order to determine what changes occurred within the soil following Norse settlement. For the Háls settlement in Western Iceland, infield soil cores containing anthropogenic soil and outfield soil cores containing non-anthropogenic soil are analyzed. The results of this analysis provide the basis for comparisons between the outfield soil core, an area that was used for grazing, to the infield soil core, and area

that was used for growing fodder. These comparisons are used to determine the changes that occurred in the Háls soil after the Norse arrived.

CHAPTER 2: BACKGROUND FOR NORSE GREENLAND AND NORSE ICELAND

2.1 NORSE GREENLAND

2.1.1 The Physical Environment of Greenland

Greenland is the largest island in the world, with a surface area of more than two million km^2 (Fristrup 1970). It extends from Cape Morris Jesup at 83°39′N to Cape Farewell at 59°46′ N (Banks 1975; Fristrup 1970). Greenland is bounded by the Arctic Ocean, Davis Strait, Denmark Strait, and the Greenland Sea (Figure 1.1).

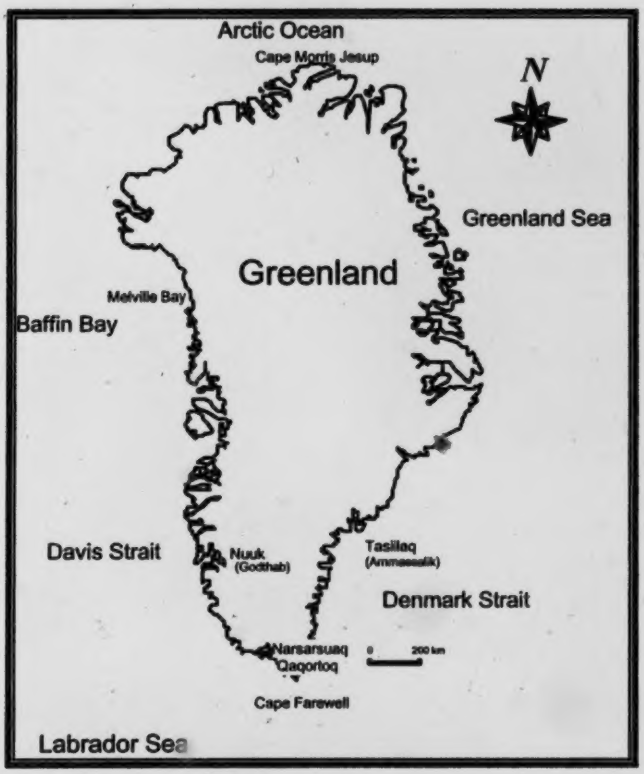
Arctic Ocean
Cape Morris Jesup
N
Greenland Sea
Greenland
Melville Bay
Baffin Bay
Davis Strait
Nuuk
(Godthab)
Tasiilaq
(Ammassalik)
Denmark Strait
Narsarsuaq
Qaqortoq
0
200 km
Cape Farewell
Labrador Sea

Figure 1.1: Map of Greenland.

Approximately 82% of Greenland's total surface area, encompassing the entire centre of the continent, is ice-covered (Banks 1975). The ice-free areas form a perimeter of 341,700 km^2 that includes fjords and steep slopes, and can be up to 400 km wide (Fristrup 1970; Hansen 1991).

The climate of Greenland varies from arctic to sub-arctic, and is characterized by cool summers and cold winters. The climate is influenced by various air masses, which originate from the central ice cap and the ocean currents (Banks 1975). As a result air temperatures on Greenland can fluctuate greatly, for example the extreme mean annual temperatures for Nuuk vary from a warm 4.7°C in 1884 to a cold 1°C in 1941 (Hansen 1991). Because of the marine influence, temperatures vary greatly between the coast and the inner fjord areas. For example, the average annual temperature in Narsarsuaq (in the inner fjord region) is 9-10°C and the average annual temperature in Qaqortoq (along the coast) is 5-6° (Hansen 1991) (Figure 1.1). Even within the same fjord, temperatures can vary between the oceanic outer coast and the continental interior. Within Nuup Kangerlua (Godthåbsfjord) the mean summer temperature on the coast is 6.7°C, while the mean summer temperature of the interior is 9.7°C (Fredskild 1981). Marine and terrestrial ecosystems of West Greenland are influenced by the mixing of two ocean currents, the Irminger Current, and the East Greenland current (Figure 1.2). The Irminger current, a warm current originating from the Gulf Stream, and the East Greenland current, a cold current originating from the Arctic Ocean, mix to form the West Greenland current (Banks 1975; McGovern 1980)(Figure 1.2). Overall, the temperature range is smaller at the coast, the temperatures are cooler, and the climate is sub-arctic. The continental climate of the inner fjord area is the only suitable place for agricultural settlements (Fredskild 1981; Hansen 1991).

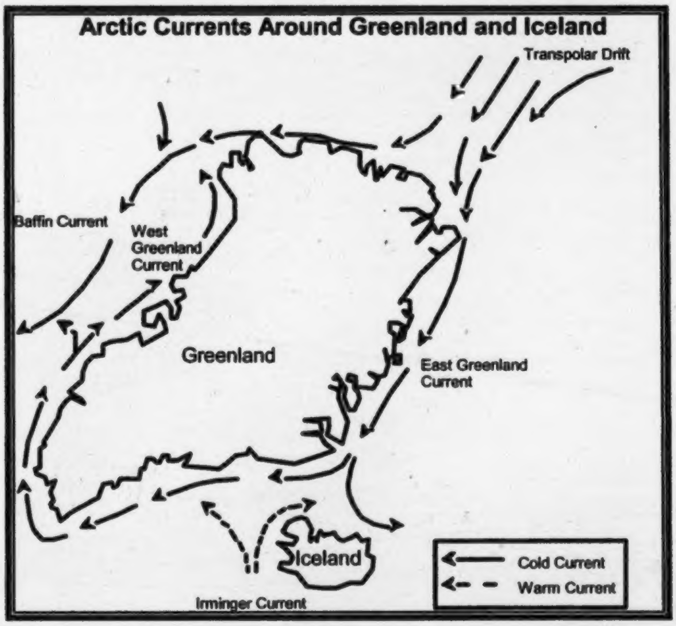
Arctic Currents Around Greenland and Iceland
Transpolar Drift
Baffin Current
West Greenland Current
Greenland
East Greenland Current
Iceland
Irminger Current
Cold Current
Warm Current

Figure 1.2: Map of the ocean currents around Greenland and Iceland (After Hermann 1970)

Precambrian crystalline rocks (i.e., gneisses and granites) dominate the geology of Greenland; there are lesser amounts of sandstone, shale and limestone. During the last glaciation, the western coast of Greenland was completely covered by ice, which retreated inland during deglaciation leaving a continuous cover of glacial deposits (Ellitsgaard-Rasmussen 1970; Funder 1989).

The Greenlandic climate determines three broad zones of vegetation: Sub-Arctic, Low Arctic, and High Arctic. The Sub-Arctic Zone is found only in the southern part of Greenland, which includes the Norse Eastern Settlement, in sheltered valleys that have average mean summer temperatures of 10°C. This zone supports Sub-Arctic, Northern

Temperate, and Boreal flora, such as birch (*Betula sp.*), alder (*Alnus sp.*), willow (*Salix sp.*), and Greenland mountain ash (*Sorbus groenlandica*). South facing slopes support grass and herb communities composed of wavy-hair-grass (*Deschampsia flexuosa*), mat-grass (*Nardus stricta*), brown-bent grass (*Agrostis canina*), Bellard's kobresoa (*Kobresia myosuroides*), crowberry (*Empetrum nigrum ssp. hermaphorditum*), and arctic blueberry (*Vaccinium uliginosum*). The Low Arctic Zone, which includes the Norse Western Settlement, occurs north of the Sub-Arctic Zone and is comprised of scrub willows, dwarf birch, and alders about as tall as a human. Here, pastures can be fully exploited for only four or five months of the year (Albrethsen and Keller 1986). The interior of the fjord supports lichens and dwarf shrubs such as arctic blueberry, and Labrador-tea (*Ledum groenlandicum*). The High Arctic Zone characteristic of northern Greenland supports dwarf shrubs and ericaceous heath (*Ericales sp.*) (Banks 1975; Bocher 1970; Fredskild 1981, 1988; Fredskild and Humle 1991; Funder 1989).

2.1.2 Settlement of Greenland

The settlement of Greenland in 985 A.D. was a result of the Norse expansion from Iceland. A hundred years earlier the search for good farmland resulted in the settlement of Iceland (Gad 1970). The history of Norse Greenland begins just after the settlement of Iceland was complete. Erik Thorvaldson, more commonly known as Erik the Red was banished from Iceland and all Icelandic territories as punishment for manslaughter. Erik the Red left Iceland in A.D. 982 and set sail in search of Gunnbjorn's skerries, which was land that had been spotted by the sailor Gunnbjorn when he was blown off-course. However, instead of finding the small group of islands that he expected, Erik the Red found a large landmass, which he subsequently named Greenland for the lush grassland areas located deep in the inner fjords. Upon returning to Iceland, Erik the Red made arrangements for the permanent settlement of Greenland. To the Icelandic Norse who were running out of arable land, Greenland must have presented an irresistible opportunity for settlement (Jones 1987).

In A.D. 985, 25 Icelandic ships sailed to settle Greenland, however because some ships turned back during storms and others were lost at sea, only 14 ships reached Greenland. The settlers took with them everything they would need to colonize Greenland, including cattle, sheep, and goats. Upon arriving in Greenland, the Norse settlers established two communities. The Eastern settlement was located in the Southwest inner fjords, near the present-day cities of Qaqortoq and Narssaq (McGovern 1994) (Figure 1.3).

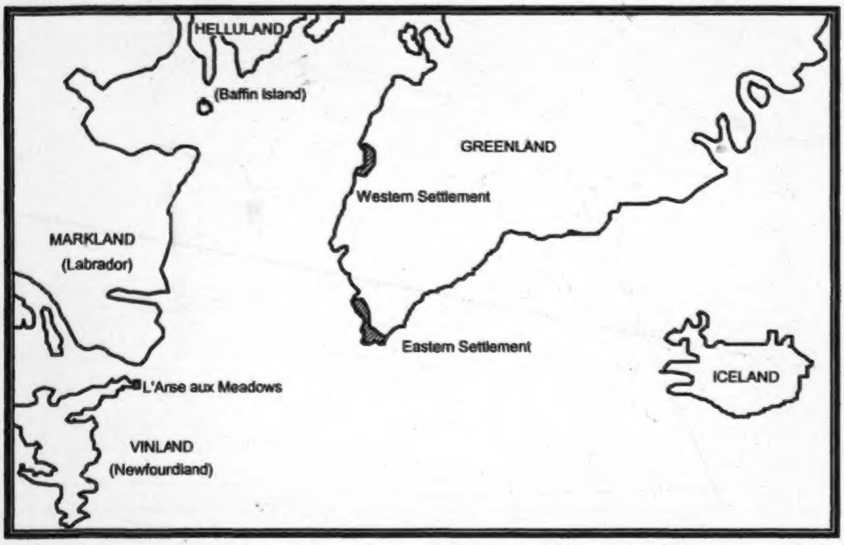
HELLULAND
(Baffin Island)
GREENLAND
Western Settlement
MARKLAND
(Labrador)
Eastern Settlement
L'Anse aux Meadows
ICELAND
VINLAND
(Newfourdland)

Figure 1.3: Map of the settlements in Norse Greenland (After Bakken 1999).

The Eastern settlement, where Erik the Red settled, grew to be the religious center of Norse Greenland as it was the larger settlement with a population of about 4,000-8,000 people (McGovern 1980, 1981). This settlement included a cathedral, a convent, a monastery, 12 churches, and approximately 190-220 farms (Jones 1987; Krogh 1967; Vebæk 1991).

The smaller Western Settlement developed approximately 400 km north of the Eastern settlement (Berglund 1986) and included at least 90 farms and 4 churches (Jones 1987), with a population of approximately 1,000-1,700 (McGovern 1980, 1981). The Western Settlement was located in the area of present-day Nuup kommunea (Godthåb district) (McGovern 1981), which now incorporates the modern capital of Greenland, Nuuk (Buckland et al. 1996).

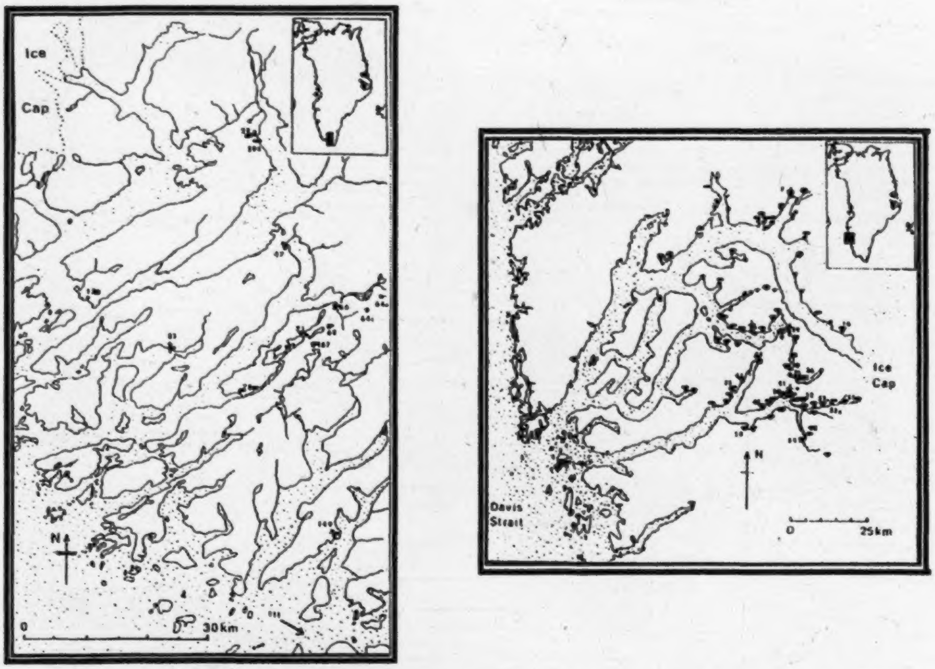

Figure 1.4: East and West Settlements in Greenland showing locations of farms and churches within the fjords (after McGovern 1985).

The inner fjord areas, where vegetation was suitable for pasturing domestic animals are where most Greenlandic Norse sites are located (Figure 1.4). In 985 A.D., when the

Norse arrived in Greenland, they found vegetation that was very similar to that of Iceland, however, Berglund (1986) characterizes the Greenlandic vegetation as "better". Although, the native vegetation was initially comprised of birch thickets, dwarf willows, and heaths, it changed soon after the Norse arrived (Fredskild 1973, 1988; McGovern 1994; McGovern et al. 1988). Grasslands and sedge meadows replaced the native vegetation (Fredskild 1973). The record of this change is provided by fossil pollen analysis of the GUS palaeosol discussed later in detail (Figure 1.5).

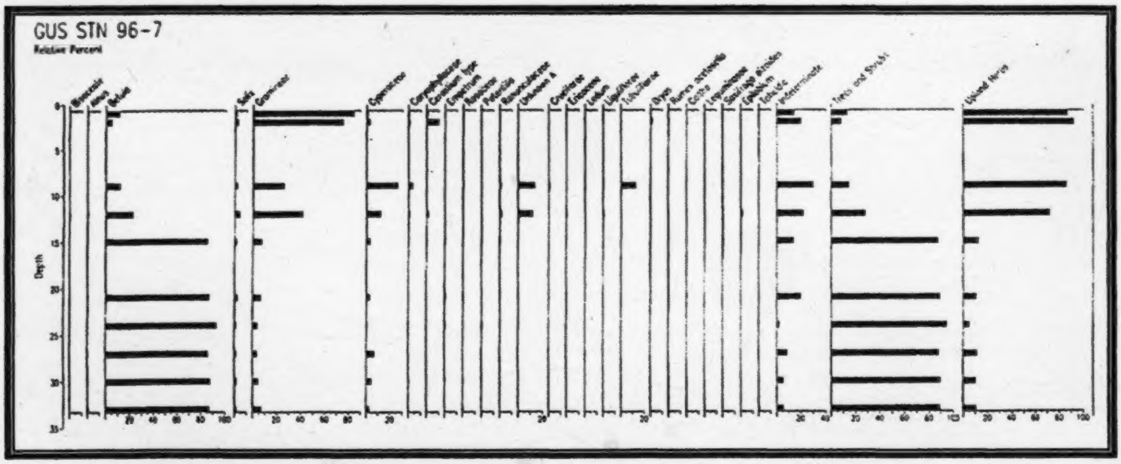

Figure 1.5: Pollen diagram from GUS palaeosol and anthropogenic soil (Unit 2 and 3, see ahead). Destruction of the birch woodland and development of grassland is indicated by a change in pollen at 13 cm (Schweger unpublished data)

2.1.3 Historical Developments in Greenland

The establishment of a diocese was one of the most important events that occurred during the Norse occupation of Greenland. A Greenlandic representative was sent to Norway during the early part of the twelfth century to petition the King for a Bishop who would oversee their diocese. As part of the petition for a Bishop substantial gifts of ivory, skins, and a live polar bear were sent to the King of Norway and to the church in Rome. Bishop Arnald arrived in 1126 A.D. (Gad 1970). His arrival indicates a sustainable and thriving community that was able to the commit to continual support of the Bishop through tithes and taxes.

Although the establishment of a bishopric initially reflected the community's economic prosperity, his presence may have eventually contributed to the "feudalization" (Berglund 1986) of Greenlandic society. According to Einar Sjkkason's saga, " the bishop became an active player in Greenlandic elite politics, eventually causing the deaths of most of the important men in the eastern settlement" (McGovern 1994). These deaths of the upper class farmers, who had been the principal landowners, resulted in land ownership shifting to the church, which then became the principal landowner (Berglund 1986). Berglund (1986) calls this power shift, where the social system becomes institutionalized and a centralized authority is established, the feudalization of society.

In 1261 A.D. Greenland lost its independence and fell under the rule of Norway which guaranteed certain benefits, one of which was that at least two ships would be sent to Greenland each year (Ross 1997). However, Gad (1970) observes that after 1367 A.D. there are no records of Norwegian ships departing for Greenland. Berglund (1986) speculates that Norway no longer needed to make the perilous journey to Greenland as the main trade items, furs and ivory, could be more easily obtained elsewhere. Unfortunately, the decline in trade would have resulted in Greenland's political, cultural, and religious isolation from their European counterparts.

In A.D. 1002, Lief Eriksson, the son of Erik the Red, purchased a crew and vessel, and set sail to find the land west of Greenland that Bjarni Herjofsson, an Icelander, had reported. Eriksson's party sailed north up the west coast of Greenland and then crossed the Davis Strait in order to reach this new land, which Eriksson called Helluland (Baffin Island). From there, they traveled southward along coasts, which they named Markland (Labrador) and Vinland (Newfoundland) (Figure 1.3). Although Lief Eriksson and his crew remained in this land for a year, they did not establish permanent settlements. However, as late as the 1340's, ships from Greenland sailed to Markland for timber (Gad 1970).

Written records on Greenland end in the early part of the fifteenth century, approximately 40 years after the arrival of their last Bishop in 1368 A.D. A church record from 1406 A.D. records that a man was burnt at the stake for practicing witchcraft, while a 1408 A.D. record describes the marriage of an upper class couple (Berglund 1986).

2.1.4 The End of Norse Greenland

Archaeological evidence indicates that the Norse Greenlandic settlements lasted until the end of the 15th century. Through the use of ^{14}C dating and the documentary evidence provided by Ivar Bardarson, steward of Gårdar between 1341 and 1363 A.D., the abandonment of the Western settlement has been dated circa 1350 A.D. (Barlow et al. 1997; Berglund 1986). However, the Eastern settlement appears to have lasted an additional 100 years and the consensus among archaeologists is that the Eastern Settlement had completely died out by 1500 A.D. (Barlow et al. 1997; Berglund 1986; Buckland et al. 1996; Gad 1970; McGovern 1980; Ross 1997). The abandonment of the Greenlandic colonies was not noticed by Europe until 1721 A.D. when Hans Egede traveled to Greenland in order to establish a mission (Lidegaard 1970). Since then many theories accounting for the abandonment of the settlements and the disappearance of the settlers have been developed.

The disappearance of the Norse from Greenland has been attributed to pirate attacks (Berglund 1986; Jones 1987; McGovern 1980), degeneration of the population through endogamy (Norlund and Stenberger 1934), competition from Inuit populations (which was the belief of Ivar Bardarson, the steward at the Episcopal see of Gårðar) (Barlow et al. 1997), plague (McGovern 1981), declining trade with Europe (Gad 1970), caterpillar infestations, climate change (Barlow et al. 1997; McGovern et al. 1988), unsuccessful adaptation to the changing climate (McGovern et al. 1988), gradual emigration from Greenland (Gad 1970; Jones 1987), the exhaustion of soils and the destruction of the vegetation (Albrethsen and Keller 1986; Berglund 1986; Krogh 1982; McGovern et al. 1988). Jacobsen (1987) has postulated that non-sustainable use of the land was the major downfall of the Norse settlements; "... until now archaeologists have not understood that the reason for the abandonment of these farms was undoubtedly soil wind erosion caused by overgrazing of the whole environment." More recently, researchers have been considering a combination of environmental and social factors to explain Norse Greenlandic extinction. McGovern (1994) has proposed that decisions made by the elite in Norse society combined with changes in the environment led to the demise of the Norse Greenlandic Settlements. The "human managers failed" to choose successful responses to the climatic stresses, which ultimately led to the decline of the Norse population in Greenland (McGovern 1981).

2.1.5 Palaeoeconomy of Norse Greenland

The Norse in Greenland practiced a pastoral agricultural economy mixed with hunting and fishing. The agricultural economy was important to Norse society as the pattern of settlement reflects choices that include good pastures. The farms are located in the inner fjord areas where the best pastures are located (Figure 1.4). At settlement, the best pasture areas were occupied first. The less productive pastures were occupied by late arrivals and subsequent generations (Christensen 1991a). The farms are normally spaced about two to five kilometers apart (Christensen 1991a; McGovern 1985) and were situated on the south-facing grassy slopes on the northern side of the fjords, which provided shelter and maximum daylight (Jacobsen 1987).

On Greenland, the Norse settlements can be divided into three types: inner fjords farms, the inland farms, and the coastal farms. Inland farms specialized in caribou hunting as the domestic caprine flocks and bovine herds were limited in size on the less productive pastures. Coastal farms specialized in sea-mammal hunting, and maintaining small flocks and herds on the limited pastures along the coast (Berglund 1986). All three types of farms would interact through the exchange of goods. Archaeological evidence shows that inland farms were heavily dependent on seals even though the farms were several hours walk from coastal farms (McGovern 1980).

2.1.5.1 The Farm Unit:

The Norse farm can be divided into four parts: farm buildings proper, infield, outfield, and saetars, small shelters located in upland areas.

Throughout the occupation of a farm, the house and byre may have undergone changes according to the needs of the farm at any time. At the time of settlement the houses appear to be typical Viking longhouses like those in Scandinavia, with a central hearth and benches along each wall (Gad 1970, Jones 1987; McGovern 1985; McGovern and Jordan 1982). These longhouses were replaced by centralized dwellings where rooms connected to the living quarters would house the animals (McGovern et al 1983). This type of building, the centralized house, was developed in Greenland and would have provided the occupants protection against the cold (McGovern et al 1983).

The infield that surrounds the house and byre was used primarily for growing fodder that supported the animals during the winter. On other Viking farms in the North Atlantic and on mainland Europe, the infield would be used for growing cereal crops, but this was not feasible in Greenland because of the climate. Although, cereal crops could not be grown, the infield was still very important to the survival of the farm. The majority of the winter fodder would be harvested from the infield and used to feed the animals during the winter. The infields were irrigated, and the ditches are still visible on the landscape (Berglund 1986). Even today, on some farm ruins, lush vegetation still grows in what was the infield area, which indicates that the farmers may have fertilized the infields to increase their fertility (Jacobsen 1987; Ross 1997:20). Fertilization of the infield would occur after the animals were released from the byres in the spring and manure from the winter would be removed and applied to the infield (Albrethsen and Keller 1986; Ross 1997). A wall or some kind of enclosure was maintained to keep the animals out of the infield. Archaeologists have rarely found traces of walls or fences so animals must have been kept out of the infield area in the summer by herders and dogs, who moved herds and flocks from one distant pasture to another throughout the summer (Albrethsen and Keller 1986).

The outfield included any area outside the infield to the furthest reaches of the farm. This area made up the pasture used to graze the animals during the summer. Extra fodder would be gathered from the outfield if the production of fodder from the infield was insufficient to feed the animals through the winter. Farming activities such as herding, milking, and foraging could be done at sæters in the outfield if the distance from the byre was too far.

Sæters, small enclosures located in the mountain uplands surrounding the farms, served a number of purposes allowing certain chores to be done away from the farm proper. There were three basic types of sæters characterized by their functions: full sæters, milking sæters, and haymaking sæters (Albrethsen 1991). Full sæters would have been occupied by animals and people throughout the summer. All summer farming activities would be carried out at this sæter. Milking sæters were used to milk the animals while they were in the outfield. The milk was taken to the permanent farmstead for processing. Haymaking sæters were used only for the collection of winter fodder and were occupied only during the periods of haymaking.

2.1.5.2 Resources available to Norse Greenlandic farms

When the Norse settled Greenland they brought with them their livestock: cattle, sheep, pig, goat, horse, and dog, which were the basis of their economy. Cattle were dually important, as part of the Norse economy and as a symbol of status and wealth, and therefore the location and layout of the farms were chosen in regard to the requirements of cows. The secondary products of cows and caprines, mostly milk, cheese, sour milk, and butter formed a large part of the Norse Greenlandic diet (Fredskild 1988).

2.1.5.2.1 FLORAL RESOURCES

There is no evidence of garden products being cultivated and forming part of the diet of the Greenlandic Norse (Berglund 1986). Greenlandic summers, which last from June to August, are too short to grow any cereal crops; saga sources and pollen data suggest that cereal production was attempted, but failed (McGovern 1981). Wild plants made up the vegetable portion of the diet. Buckland et al (1996) have frequently found crowberry (*Empetium migrum)* and bilberry (*Vaccinium uliginosum*) seeds in middens. There have been fragments of seaweed found preserved inside buildings, including GUS, which indicates that it may have been used as food (Albrethsen and Ólafsson 1998; Buckland et al. 1983; McGovern et al. 1983).

2.1.5.2.2 FAUNAL RESOURCES

Since the Norse Greenlanders could not grow grain crops or have gardens, meat and dairy were important parts of the diet. The Norse kept domestic animals but also exploited wild animals. The Norse agricultural economy was based on pastoralism, primarily cattle, sheep, and goats. These ungulates were kept for their secondary products (e.g. milk, wool) rather than their meat (McGovern and Jordan 1982). Cattle were very important to the Norse economy, not just for their products, but also as a status symbol in the whole North Atlantic region (Fenton 1978; McGovern 1980; McGovern et al. 1988). One's status as a freeman was determined by the number of cattle owned (Ingimundarson 1995; Zutter 1997). Raising cattle is labour intensive as cattle require shelter in the winter and a large amount of fodder, about 4,200 kg/yr/animal (Albrethsen and Keller 1986; McGovern et al. 1988). Sheep and goats also required fodder during the winter, but only about 1/6th as much as cattle (Christensen 1991b). Also caprines could be left grazing outdoors much later in the fall (Albrethsen and Keller 1986; McGovern 1980).

Other domestic animal remains, such as pig, horse, and dog, have been recovered from archaeological excavations (Appendix 1). The quantity of bone that is recovered from these species is low suggesting that these animals did not contribute much to the Norse Greenlandic diet.

The Norse Greenlanders also made use of a variety of local wildlife, predominantly seal and caribou, (McGovern and Jordan 1982; McGovern et al. 1996). Both maritime and terrestrial environments were exploited (Appendix 1). There was heavy reliance on seal (up to 30% of the bone fragments) even on farms located several hours walk from the ocean (McGovern 1980). Other species exploited from the maritime environment include whales, walrus, fish, and shellfish all of which occur in low frequencies in the archaeological record (Barlow et al. 1997; McGovern 1985). Fish could have contributed greatly to the Norse diet although there is a lack of fish remains in most faunal assemblages. This may be a result of decomposition processes, recovery techniques, or may accurately reflect the contribution that fish mad to the Norse diet. They note that the absence of fish remains, fishing equipment, and evidence of immature seals indicates that although the Norse lived in a maritime environment, they did not possess the equipment or the technology to exploit the maritime resources to their fullest extent.

Terrestrial animals (caribou, polar bear, hare, fox, wolf), and a variety of birds were exploited. Caribou was the most exploited of the terrestrial animals and could be hunted in the fall when the animals were migrating out of the fjord areas. Polar bear, hare, fox, and wolf appear in the faunal record in low frequencies, indicating their limited contribution to the Norse Greenlandic diet. Birds do not appear to be a large component of the Norse Greenlandic diet. Those birds that do appear in the faunal assemblage are ptarmigans, seabirds, and raptors (McGovern 1985). The ptarmigan and seabirds were probably caught for food, but the raptors were probably caught for trade or killed to protect livestock.

GUS was an inland farm that made use of the wild and domestic animals near the farm and from the coast (Enghoff 2003). The composition of the faunal assemblage indicates that the occupants of GUS hunted birds, seals, walrus, whales, reindeer, arctic hare, arctic fox, and polar bear.

The majority (80%) of the bird bones present at GUS were those of ptarmigan (Enghoff 2003). Other species present in the faunal record in smaller numbers are geese, eiders, and auks. Seal bones made up the largest fraction of the faunal assemblage, 40% of the recovered mammals bone fragments (Enghoff 2003). Enghoff (2003) notes that all species of seal that live in Greenland waters are present in the faunal assemblage at GUS. The bones of the common seal, which could be hunted close to the farm, and the harp seal, which live along the seacoast, were the most frequent. Walrus and whale bones are present in low frequencies indicating that walrus and whale meat was consumed and whale bones were used (Enghoff 2003). Reindeer bones make up the third largest fraction of the faunal assemblage recovered from GUS. Enghoff (2003) notes the importance of reindeer at GUS decreased with time. In the early phase of GUS reindeer constituted 27% of the mammal bones, whereas in the late phase reindeer made up 12% of the mammal bones. Arctic hare bones occur consistently throughout all three phases at GUS, and occur in higher frequencies than at other Norse sites; however this is probably a result of the meticulous excavation method (Enghoff 2003). Arctic fox and polar bear bones were recovered in the faunal assemblage at GUS, but as only one bone of arctic fox and three bones of the polar bear were recovered, Enghoff (2003) suggests that these animals were not part of the diet.

The fish remains recovered from GUS make up the largest assemblage of fish remains yet to be recovered from any Norse Greenlandic site (Enghoff 2003). The most numerous species of fish bone recovered from GUS are Arctic char, cod, and capelin (Enghoff 2003). The majority of the fish bones were recovered by sieving the sediment, and most were in poor condition. Enghoff (2003) believes that the poor representation of fish bones in other excavations of Norse Greenlandic sites "... is in part caused by the excavation technique and conditions of preservation."

Caprine bones make up the second largest fraction of the entire faunal assemblage, following seal (Enghoff 2003). However, caprine bones make up the largest portion of domestic animal remains (Enghoff 2003). These animals were kept primarily for their meat and wool. Cattle bones number about ⅓ of the caprine bones. The later phase of occupation has a lower frequency of cow bones (6%) than the early phase (15%) suggesting that the importance of cattle decreased over time (Enghoff 2003). Other domestic animal bones present in low frequencies at GUS are horse, swine, and dog.

The faunal assemblage recovered from GUS is a representative sample of all fauna available in Greenland. Enghoff (2003) notes that throughout the period of occupation the ratio of wild to domestic mammals remains about 1:1. However, marine species became more important in the faunal assemblage through time, from 29% of the bones in phase 1 to 44% of the bones in phase 3 (Enghoff 2003).

2.1.5.3 Seasonal Round

McGovern (1980, 1991) used faunal assemblages to develop a model of seasonal life on a Norse farm. The Norse subsistence economy was a balanced exploitation of inner and outer fjord marine and terrestrial resources. The spring would have been the leanest season, since winter stocks would have been consumed and summer stocks were not yet available. The cattle would be let out of the barns after being confined for the entire winter. In some instances they would have to be physically carried out to the pastures (McGovern 1980). Seals would be the first resource to arrive in the spring, during May and June, and the archaeological record contains immature seals indicating a spring hunting season (McGovern 1985). The summer months would have been the busiest with milk production, haymaking, seal hunting and the *Norderestur* hunt. This hunt took place north of the settlements, and was vital in obtaining luxury items such as ivory, furs, and live raptors to trade with Europe and to pay for taxes. The Norse also traded more common items such as wool with Europe. In trade they would get necessary items such as grain, iron, and wood but also religious items such as church bells and stained glass (McGovern 1991). The caribou hunt was part of the fall activities and would have been important for filling the stores to last throughout the winter.

2.2 NORSE ICELAND

2.2.1 Physical Background

Iceland is an island country located at 65°N and 18°E, between the North Atlantic Ocean and the Greenland Sea. (Figure 1.6) The island is about 103,000 km^2 and is characterized by plateaus interspersed with mountains, volcanoes and ice-fields. The coast of Iceland is indented deeply with fjords.

Twenty-four million years ago Iceland formed as a result of the separation of the mid-continental ridge, a volcanic zone that occurs between the diverging North American and Eurasian plates. Therefore, Icelandic geology is dominated by basalt flows, which make up the oceanic crust forming the ocean floor (Thordarson and Hoskuldsson 2002). The mid-continental ridge continues to spread and as a result Iceland contains active volcanoes. In contrast to the volcanoes, a large portion, 11.5% of the island is also covered with glaciers (Bamlett and Potter 1994; Jackson 1970). This stark contrast has given rise to the description of Iceland as the Island of Fire and Ice.

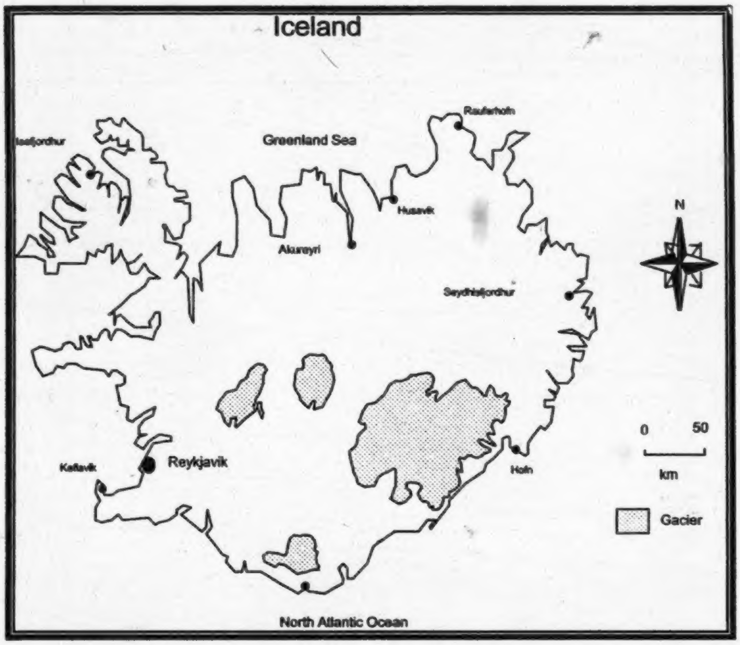
Iceland
Isafjordhur
Greenland Sea
Raufarhofn
Husavik
Akureyri
Seydhisfjordhur
N
0
50
km
Keflavik
Reykjavik
Hofn
Gacier
North Atlantic Ocean

Figure 1.6: Map of Iceland.

Iceland's soil is derived mainly from the weathering of the basalt bedrock and from volcanic ash (Arnalds et al. 2001; Jackson 1970). Organic soils such as peat forms in lowlands where the climate is cold and damp, and there is very little drainage.

Iceland lies at the confluence of the warm Irminger current and the East Iceland current both of which influence the climate (Figure 1.2). The climate is categorized as maritime cold temperate to sub-arctic, with mild winters and cool summers (Arnalds et al. 2001; Philpott 1989). For example, in Reykjavik between 1961 and 1990 the mean January temperatures averaged –0.5°C and the mean July temperatures averaged 10.5°C (Hálfdanarson 1997). The climate of Iceland is affected by four factors: 1) the boundary between the polar air mass and the tropical air mass, which can shift across Iceland determining either cool-moist or warm-dry winters in the north; 2) the North Atlantic (Irminger) current and the cold East Greenland Polar current that converge along the coast of Iceland; 3) the presence of drift ice; and 4) the positions of atmospheric depressions crossing the North Atlantic (Jackson 1970).

2.2.2 Settlement of Iceland

Iceland got its name from Floke Vilgerdson, the first Norseman to attempt to settle the island around A.D. 865. He returned to Norway one year later after watching the fjord fill up with ice and losing all of his livestock (Dansgaard et al. 1975). This experience left him with a poor impression of the island and he christened it Iceland. This name did not dissuade people from attempting to settle the island and between A.D. 870-930 people came from Norway or via the Norse settlements in the Scottish Isles to settle Iceland (Adalsteinsson 1991; Jones 1986). The first areas to be settled were along the coasts as these areas were more moderate and productive than the interior. The less productive inland area became occupied as more settlers arrived. Like Greenland, those settlers who arrived first and had the more productive farms were of higher social status. On average, the farms were two to five miles apart and confined to the valleys (Jackson 1970; McGovern 1985).

2.2.3 Social /Religious and Political Background of Iceland

Iceland has been continuously occupied since the Norse settled it in A.D. 874. Since then, Iceland has undergone changes in the social, religious and political structures. The island was influenced by mainland Europe and was Christianized not long after settlement. The *Althing,* considered to be the earliest form of parliament in Europe, was founded in A.D. 930. It was composed of chiefs from 39 *Godar* (chieftaincies) and 13 *things* (local assembles) (Hálfdanarson 1997; Jackson 1970; Scherman 1976). Politically, Iceland remained part of the Independent Icelandic Commonwealth until it came under Norwegian Crown rule in A.D. 1262. Civil war in Iceland helped the Norwegian King persuade the *Althing* that law and order would be restored under his rule. Iceland had lawbooks that regulated and legislated land tenure rights, scheduling of economic activities, land-use management, and even freeman status (Ingimundarson 1995; Zutter 1997). The treaty signed in A.D. 1262 with Norway was suppose to preserve the Icelandic law code, but it was eventually replaced by the Norwegian code by A.D. 1271 (Jackson 1970). When Norway came under Danish rule in 1380 Iceland followed and remained under Danish rule until gaining independence in 1944.

2.2.4 Palaeoeconomy of Iceland

Throughout its history Iceland has been primarily a farming country. The importance of the farming community is evident in historical documents such as the lawbook Grágás, which outlines the minimum number of cows per farm to maintain freeman status, the mandatory building and maintenance of field walls and fences, the scheduling of sheep movements to and from summer pastures, and the timing of hay-cutting (Ingimundarson 1995; Zutter 1997). Barley was the only grain able to mature in Iceland and then only in the southwest part of the island (Jackson 1970; McCririck 1976). At the time of settlement, Iceland was covered with birch forests (Adalsteinsson 1991), and like Greenland, Iceland was quickly stripped of all of its trees for charcoal, fuel and to create pastures (Figure 1.7). There were no large herbivores on Iceland before the arrival of the Norse. The largest animal was the arctic fox (Jackson 1970; McCririck 1976). There are a number of bird species that formed part of the Icelandic diet and fishing grew from subsistence to be a very important part of the market economy.

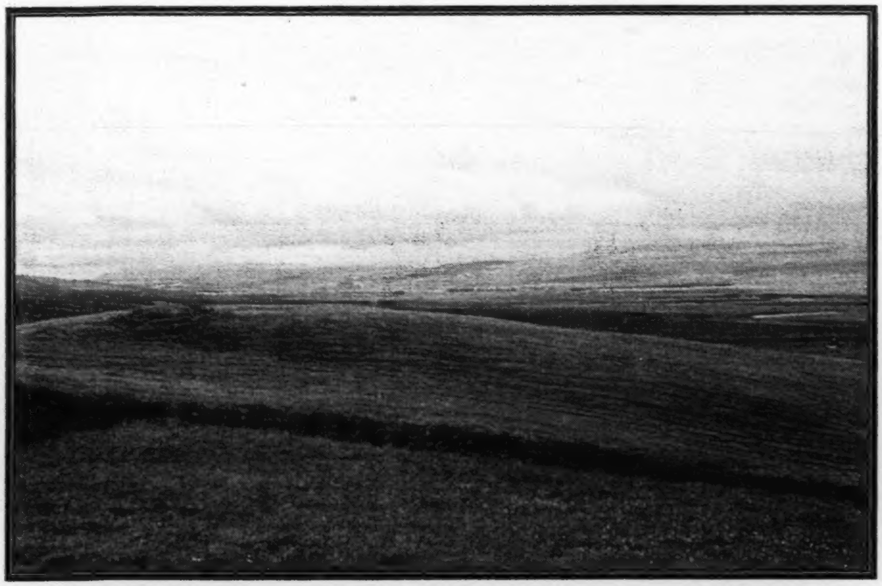

Figure 1.7: View of the area around Háls. (Photograph by author).
Note the absence of trees. The village of Reykholt is visible in the background.

CHAPTER 3: SOIL CHEMISTRY

3.1 ARCHAEOLOGICAL SOIL

Soil is "a dynamic natural body composed of mineral and organic materials and living forms in which plants grow" (Brady and Weil 2000). As human beings, we interact with soil on many different levels. We spend the majority of our time on land treading over the earth, harvesting its fruits, and then disposing of our refuse. Because of the relationship between people and the earth, archaeologists investigate palaeosols as the living floors of archaeological societies.

3.2 ELEMENTS IMPORTANT FOR PLANT GROWTH

Important elements that must be relatively abundant for plant growth are phosphorus (P), carbon (C), nitrogen (N), potassium (K), calcium (Ca), magnesium (Mg), and sodium (Na).

3.2.1 Phosphorus

Phosphorus is one of the macronutrients required by plants and is introduced to the soil by human activities such as the disposal of wastes, burials and fertilizing, and by the breakdown of plant material and phosphorus bearing rocks (Eidt 1984; Prøsch-Danielsen and Simonsen 1988). Phosphorus exists either in inorganic or organic compounds. Rocks and dust contribute only the inorganic or phosphate (PO_4^{-2}) forms of phosphorus. Organic and inorganic forms of phosphorus occur in fertilizers, and residues from plants and living organisms. The majority of phosphorus in organic form exists as ester phosphates, while nucleic acids and phospholipids make up a small portion of the total organic phosphorus compounds (Brady and Weil 2000; Eidt 1984).

Organic forms of phosphorus will eventually mineralize within the soil to become inorganic phosphates (Eidt 1984) (Figure 3.1). Soil elements Ca, Fe, and Al, tightly bind inorganic phosphates making them immobile (Eidt 1984). Because inorganic phosphates are immobile they build up during the occupation of a site by humans. Areas that have high levels of phosphate usually represent areas of human occupation.

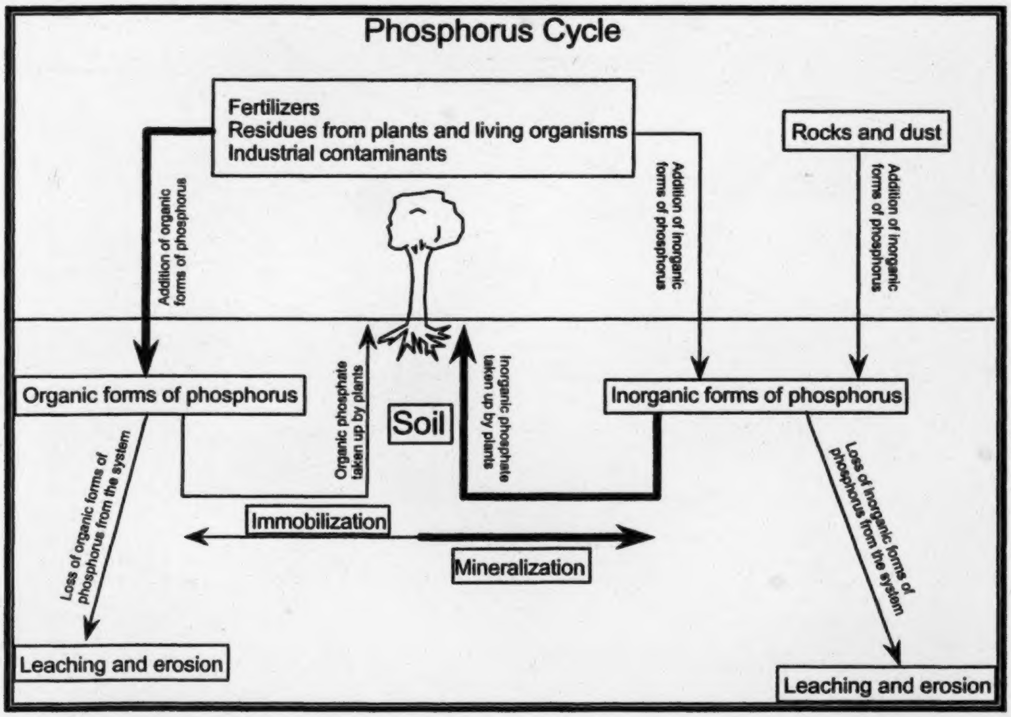
Phosphorus Cycle
Fertilizers
Residues from plants and living organisms
Industrial contaminants
Rocks and dust
Addition of organic forms of phosphorus
Addition of inorganic forms of phosphorus
Addition of inorganic forms of phosphorus
Organic forms of phosphorus
Organic phosphate taken up by plants
Soil
Inorganic phosphate taken up by plants
Inorganic forms of phosphorus
Loss of organic forms of phosphorus from the system
Immobilization
Mineralization
Loss of inorganic forms of phosphorus from the system
Leaching and erosion
Leaching and erosion

Figure 3.1: The phosphorus cycle. The heavy arrows indicate the major movement of phosphorus throughout the cycle (After Brady and Weil 2000).

Phosphate analysis of archaeological sites began in the 1920's with Arrhenius, who was the first to notice a correlation between phosphate concentrations and archaeological sites

(Eidt 1984), and has since become a common method of locating subsurface archaeological sites because it is quick and inexpensive. Phosphate analysis can also be applied to detect occupation levels within soil profiles (Schlezinger and Howes 2000). Kerr (1995) provides a complete list of applications of phosphate analysis of sediment.

Historically, palaeosol research was usually limited to the detection of archaeological sites using phosphate analysis (Orna and Lambert 1996). However recently there has been a shift towards investigating anthropogenic soil as an archaeological artifact (Henriksen and Robinson 1996; Simpson 1993, 1994, 1997; Simpson et al. 1999). Soils used for agriculture should show evidence of soil modification to support crops, which includes changes in concentrations of phosphorus, carbon, nitrogen, and exchangeable cations.

3.2.2 Carbon

Carbon is one of the building blocks of life and soil carbon is derived from the decomposition of plant litter, animal remains, and the incorporation of atmospheric carbon by soil micro-organisms. Carbon can be ingested by organisms and expelled as CO_2, which plants use during photosynthesis. The carbon content of soil is a reflection of the biomass (the total mass of living material of the environment) production.

3.2.3 Nitrogen

Nitrogen, a macronutrient required by plants, makes up about 5% of soil organic matter (Brady and Weil 2000). Nitrogen is incorporated into the soil from rainwater, the breakdown of organic residue during microbial decomposition, and the fixation of atmospheric nitrogen (N_2) (Figure 3.2). Nitrogen exists in organic or inorganic forms, but plants use only the inorganic form of nitrogen. Only a small amount of nitrogen is naturally available to plants in inorganic forms, NH_4^+ and NO_3^- (Singer and Munns 1996). This form of inorganic nitrogen is returned to the soil through precipitation, but is considered too small to be relevant to crop production (Stevenson 1982).

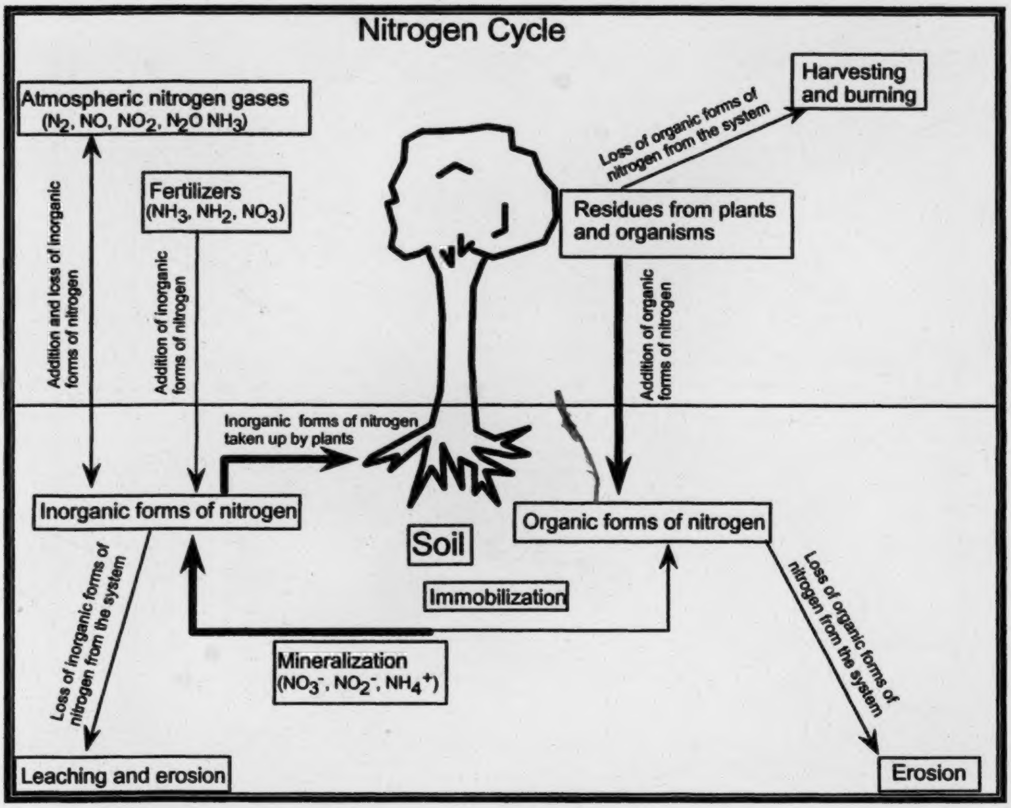
Nitrogen Cycle
Atmospheric nitrogen gases
(N2, NO, NO2, N2O NH3)
Harvesting and burning
Loss of organic forms of nitrogen from the system
Fertilizers
(NH3, NH2, NO3)
Residues from plants and organisms
Addition and loss of inorganic forms of nitrogen
Addition of inorganic forms of nitrogen
Addition of organic forms of nitrogen
Inorganic forms of nitrogen taken up by plants
Inorganic forms of nitrogen
Organic forms of nitrogen
Soil
Immobilization
Mineralization
(NO3-, NO2-, NH4+)
Loss of inorganic forms of nitrogen from the system
Loss of organic forms of nitrogen from the system
Leaching and erosion
Erosion

Figure 3.2: The nitrogen cycle. The heavy arrows indicate the major movement of nitrogen throughout the cycle (After Brady and Weil 2000).

However, the major source of soil nitrogen for plant use comes from the decay of organic matter. This organic form of nitrogen undergoes a complex process called mineralization where it is converted into inorganic nitrogen by soil micro-organisms. Only about 1- 3% of organic nitrogen mineralizes annually, and this is considered to be sufficient for normal plant growth (Brady and Weil 2000). The micro-organisms may require more nitrogen than is available from organic sources. When this occurs the micro-organism makes use of inorganic forms of nitrogen, in a process called immobilization. This process removes inorganic forms of nitrogen from the soil. Mineralization and immobilization occur concurrently. However one may dominate depending upon the carbon to nitrogen ratios of the organic residues undergoing decomposition (Brady and Weil 2000). The ratio of carbon to nitrogen in the soil is important in determining whether inorganic nitrogen will be available for plants. (For a more thorough explanation of the Nitrogen Cycle see Brady and Weil (2000).

Another source of soil nitrogen comes through the biological fixation of atmospheric nitrogen by organisms that are capable of breaking the N_2 triple bond. There are three ways organisms can fix atmospheric nitrogen: 1) symbiotic fixation with legumes, 2) symbiotic fixation with non-legumes, and 3) non-symbiotic nitrogen fixation. These are briefly explained below.

3.2.2.1 Symbiotic fixation with legumes

A symbiotic relationship exists between legumes and bacteria (of the *Rhizobium* and *Bradyrhizobium* genera), which provides carbohydrates and water to the bacteria and nitrogen to the plant (Brady and Weil 2000). The bacteria form nodules on the roots of the legume that serve as the site of nitrogen fixation. The bacteria convert atmospheric nitrogen into an inorganic form (NH_4^+) usable to plants. The absence of either the bacteria or the legume will inhibit fixation of atmospheric nitrogen. The Fabaceae (formerly Leguminaceae) family contains 10,000 to 12,000 species, most of which are indigenous to the tropics. Legumes, except for *Astragalus alpinus* subsp in Arctic Greenland, are only present in the southern portion of Greenland (Boris Alexandrovich Yurtsev, Komarov Botanical Institute, St. Petersburg, personal communication 2003).

3.2.2.2 Symbiotic fixation with non-legumes

In this case, bacteria form a symbiotic relationship with plants that are not legumes. The soil bacteria, actinomycetes, within the genus *Frankia*, can infect the roots of about 200 non-leguminous plants to form nodules. Cyanobacteria can form a symbiotic relationship with non-legumes without the formation of nodules. The location of fixation occurs on the stems or leaves.

The symbiotic relationship with *Frankia* can occur with several cool temperature or arctic plants, *Betula, Alnus*, and the Rosaceae genera *Cerocarpus*, *Dryas* and *Parshia* (Stevenson 1982). *Betula* was abundant on Iceland (Zutter 1997) before Norse settlement, but dwindled after settlement occurred. The symbiotic fixation of atmospheric nitrogen would have been possible if *Frankia* was present.

3.2.2.3 Non-Symbiotic Nitrogen fixation

Non-symbiotic nitrogen fixation is limited to organisms that are able to fix atmospheric nitrogen without the aid of a host plant. Heterotrophic organisms (ie lichens, which are fungi/algae combination) exist in temperate and tropical soils, and the autotrophic (photosynthetic) organisms such as algae live in wetlands and anaerobic soils. These organisms are capable of fixing carbon dioxide and nitrogen simultaneously (Brady and Weil 2000).

Because the majority of nitrogen used by plants is derived from in soil organic matter, soil nitrogen can be easily depleted when there is removal of biomass from the area. Inorganic nitrogen seldom accounts for more than 1-2% of the total nitrogen content in the soil (Brady and Weil 2000). Nitrogen can be lost from soil through erosion, leaching, denitrification and volatisation, harvesting, and burning of plants. Erosion affects the loss of the nitrogen rich litter and humus, while leaching affects mostly the inorganic forms of nitrogen (especially nitrate), which are more soluble than the organic forms. Denitrification and volatisation refers to the loss of nitrogen as gas to the atmosphere. Nitrogen gas can also be lost during the burning of plants (Brady and Weil 2000). However, plants extract nitrogen from the soil for use in biological processes, the nitrogen is returned to the soil once the plant dies and decays. Harvesting plants or crop cover therefore removes nitrogen from soil.

3.2.2 Exchangeable Cations

There are four exchangeable cations that will be investigated in this thesis: Ca^{2+}, Mg^{2+}, Na^{+}, and K^{+}. These four cations make up 99% of all cations in many soils and are required for healthy plant growth. These elements can come from the weathering of minerals, mostly amphiboles and feldspars, and the decay of organic matter (i.e.: plants, dung, and animal remains). They exist in cationic form, and are adsorbed and held electrostatically on the negatively charged surfaces of colloids within the soil and are not easily lost with leaching water (Singer and Munns 1996). The colloids can either be organic humus, or inorganic clay. The quantity and kinds of colloids in the soil will directly affect the quantity of cations. A sandy soil will have very few cations compared to a colloidal rich peat.

3.3 MAINTENANCE OF SOIL FERTILITY.

It is necessary to maintain a balance of nutrients in the soil-plant ecosystem or plant life will not be viable. This is an important consideration for field soils, as crop production is determined by the fertility of the soil and nutrients are removed from the system during harvest. Over time nutrients are returned to the system naturally through rainfall, redistribution of organic and inorganic matter by erosion and wind, and through the continual weathering of rocks and minerals. Each year the small amount of nutrients introduced through these processes is usually just enough to offset the loss of nutrients through natural leaching.

Organic fertilizers, made up of decaying plant material and animal dung release nutrients into soil. Generally, 95% of the total plant nutrients consumed by animals are excreted in their urine and feces (Powel et al. 1994). Seaweed is also an organic fertilizer used along coastal areas around the world, to maintain soil productivity. Animal manures, human waste excrement, household waste and seaweed would have been available to the Norse on Greenland and Iceland. Hallsson (1964) notes that the earliest recording of edible seaweed comes from an Icelandic saga (circa 961 A.D.). By the beginning of the 12th century, the right to collect seaweed was regulated by the law, and once collected, seaweed appears to have been transported for use over long distances.

The addition of seaweed is especially beneficial to sandy soils, which are low in organic matter and weak in soil structure, and important for peat soils (Fenton 1985). Seaweed makes a good natural fertilizer as it not only contains essential nutrients, but it breaks down rapidly (Bell 1985). Fenton claims that cattle and sheep prefer the grass from fields fertilized by seaweed over grass from fields on which seaweed was not applied, and the animals thrive faster and fatten sooner. Chemically, seaweed is similar of animal manure although seaweed has about a third of the phosphorus and twice the potassium content of farmyard manure (Table 3.1). As such, prolonged use of seaweed as a fertilizer can create chemical imbalances in the soil (Fenton 1985).

Table 3.1: Comparison of animal manures to seaweed.

Nutrient	Manure (% Dry weight)	Seaweed (% Dry weight)
Nitrogen	1.4-4.4	0.96-3.1
Phosphorus	0.4-2.1	0.09-0.56
Calcium	0.5-2.3	0.72-2.16
Magnesium	0.2-1.0	0.39-0.82
Potassium	1.0-2.6	2.26-8.15
Sodium	N/A	1.35-2.9

Manure represents horse, cow, sheep, swine and poultry manures. Seaweed data for *Cladophora rupestris, Rhodymenia palmate, Laminaria cloustoni, Laminaria cloustoni*, and *Ascophyllum nodosum*. Data is compiled from (Brady and Weil 2000; Johnston 1971; Stephenson 1973).

3.4 GREENLAND SOIL

The soils of Greenland have formed over the last 10,000 years or since deglaciation, and are restricted to the present ice-free zones. All soils in Greenland have developed from coarse-textured tills or glacio-fluvial materials, both of which are covered by a mantle of late glacial loess (Jakobsen 1991a)[3]. The soils of Greenland can be divided into three broad categories; 1) Polar Desert soil occurs in the very north of Greenland; 2) Brown soils (Arctic and Subarctic) occur in the eastern and western parts of Greenland; and 3) Podzols occur in the east, west, and southern parts of Greenland (Charlier 1969; Jakobsen 1991a, b, c, 1992; Ugolini 1966). However, the soil types are not confined to these areas and tend to overlap one another. Subarctic Brown soil, Podzolized Subarctic Brown soil, and Subarctic Podzols all occur in southwestern Greenland (Jakobsen 1991c). The soils in southwest Greenland are generally acidic, sandy, strongly organic, high in exchangeable cations (Rutherford 1995), and show development of eluvial and illuvial horizons indicating podzolization (Jakobsen 1991a). Podzols are strongly to moderately acidic and have a distinct eluvial E-horizon and illuvial B-horizon, which develops from the "translocation of metal cations by water soluble organic acids" (Jakobsen 1991b, c). Therefore, they have a thin organic-mineral layer above a leached A-horizon and a dark brown B-horizon, which is enriched in iron oxide, alumina, and organic matter.

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[3] Jakobsen (1991a and b) follows the Food and Agriculture Organization (FAO) 1977 guidelines for soil profile description. Jakobsen 1991c follows Tedrow 1977 guidelines for arctic soils.

3.5 ICELAND SOIL

The soils of Iceland differ from those of Greenland as a result of the different geology. Ninety percent of Iceland consists of volcanic rocks. Volcanic activity ejects large quantities of tephra into the atmosphere, which settles over the landscape and greatly affects the character of the soils, a process that continues today (Arnalds et al. 1995)[4]. Like Greenland, the soils in Iceland have developed over the last 10,000 years or since deglaciation. The soils of Iceland are categorized as Andisols because of their volcanic origin. Andisols are highly susceptible to erosion, (Arnalds 1999; Arnalds et al. 1995), are moderately acidic, and have high Cation Exchange Capacities (CEC) (Arnalds et al. 1995). Andisols in Iceland are divided into two general categories: poorly drained and freely drained (Helgason 1968).

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[4] Arnalds et al (1995) follow the Soil Survey Staff (1992) classification of soils.

CHAPTER 4: STABLE ISOTOPES

4.1 INTRODUCTION:

Isotopes are " two or more atoms of the same element that have different atomic masses because of different numbers of neutrons in the nucleus." Therefore all isotopes of an element react the same chemically but differ in weight. Stable isotopes are those that remain unchanged over time.

While weight does not affect the way the element reacts chemically, it does make a difference during kinetic reactions. Reactions involving two atoms of the same element but of different weights (isotopes) will take place at different rates. The lighter isotope will react more quickly that the heavier. The different rates of reaction can result in differential concentrations of isotopes in the reactant and product. The process that creates the differential concentrations of isotopes is termed fractionation and will only occur if the reaction does not involve all of the reactant. If the chemical reaction uses all of the reactant, no fractionation will be evident, as the heavier and lighter isotopes will no longer form a ratio dependant on their relative weights.

4.2 STABLE ISOTOPE APPLICATIONS TO ARCHAEOLOGY

Application of stable isotope research to archaeology began in the late 1970s (DeNiro and Epstein 1978, 1981; van der Merwe and Vogel 1977), and has mostly been applied to palaeodiet reconstruction (Herz 1990; Sillen et al. 1989; van der Merwe and Vogel 1977).

Archaeological studies have concentrated on the analysis of bone collagen for stable isotopes of carbon, nitrogen, and strontium. Ratios between ^{12}C:^{13}C and ^{14}N:^{15}N are employed to distinguish the different types of terrestrial plants, and marine organisms. Carbon isotopes are used to distinguish between C_3 and C_4 plants, and between aquatic and terrestrial components of diet. Nitrogen isotopes are used to distinguish trophic levels and between leguminous and non-leguminous plants (Sillen et al. 1989). Strontium isotopes are used to distinguish the meat to plant proportions of diet.

Palaeodiet reconstruction relies on the fractionation of the isotopes in metabolic processes. Terrestrial plants can be divided into three groups according to their metabolic processes: C_3, C_4, and CAM plants (DeNiro and Epstein 1978; Sillen et al. 1989; Tauber 1981). Each metabolic process fractionates isotopes differently. C_3 plants are depleted in the heavy ^{13}C isotope and have $\delta^{13}C$ values around -26‰, but can range between –21‰ and –35‰ (Figure 4.1, Table 4.1). C_4 plants are not as depleted in ^{13}C, and have $\delta^{13}C$ values around –12.5‰, but can range between –14‰ and –10‰ relative to Peedee Bellemnite- the international standard (Figure 4.1). Legumes and non-legumes can be distinguished by their $\delta^{15}N$ values. Legumes fix atmospheric nitrogen so their $\delta^{15}N$ values will be similar to air, around 0‰. Non-legumes are depended on soil derived nitrogen so their ^{15}N values tend to be more enriched, i.e. $\delta^{15}N$ is around 3‰ (Table 4.1) Aquatic foods can also be distinguished from terrestrial foods by their $\delta^{13}C$ and $\delta^{15}N$ values. Aquatic plants have $\delta^{13}C$ values around -19‰, and $\delta^{15}N$ values around 7‰ (Table 4.1). (Herz 1990; Kelly 2000; Peterson and Fry 1987; Tauber 1981)

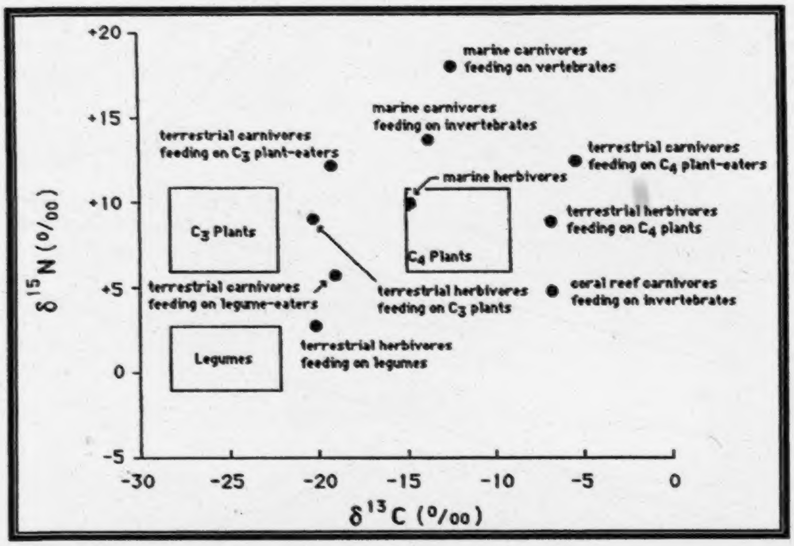

Figure 4.1: Carbon and nitrogen isotope values for bone collagen (From Herz 1990).

Through feeding experiments DeNiro and Epstein (1978) demonstrated the influence of diet on the carbon isotope composition of animals. Their findings revealed that the whole body of the animal was only enriched in ^{13}C on average by about 1‰. The $\delta^{13}C$ value of the whole body of the animal reflected that of the diet and could therefore be used to determine the make up of the diet. However, isotopic fractionation occurs at different rates within different tissues of the animal. Whereas the whole body of the animal is only slightly enriched in $\delta^{13}C$, the bone collagen is enriched by 4‰ to 6‰, and lipids are depleted by 2‰ to 8‰, while muscle has the similar $\delta^{13}C$ composition of the diet (Kelly 2000; Peterson and Fry 1987).

The fractionation of nitrogen isotopes can divide terrestrial plants into two groups: Legumes and non-legumes. Legumes and blue-green algae have lower $\delta^{15}N$ values because they get their nitrogen from the atmosphere as opposed to the soil. Different degrees of fractionation of nitrogen isotopes occurs between marine and terrestrial organic material. Fractionation of nitrogen isotopes enables researchers to determine trophic levels, because at each tropic level an organism becomes enriched in ^{15}N by 3‰ to 5‰ (Peterson and Fry 1987). Like carbon, nitrogen isotopes can fractionate at different rates according to the tissue. For example, cow milk and blood is enriched in ^{15}N by 4‰, urine is depleted by –1 to -4‰, and feces are enriched by 2‰ versus diet (Peterson and Fry 1987). The δ^{15}N in the tissues is offset by the release of the lighter isotopes through respiration and excretion

4.3 STABLE ISOTOPES AND SOILS

Stable isotope analysis can be used to investigate the environment of soil formation. For example, soils near the ocean will reflect the δ^{13}C values of the marine environment because of the input of marine detritus, and if a field grew maize, the soil will have the δ^{13}C values near that of maize, a C_4 plant (Boutton 1991).

Table 4.1: The average and range of δ^{13}C and δ^{15}N in nature.

Source	δ^{13}C ‰ average	δ^{13}C ‰ range	δ^{15}N ‰ average	δ^{15}N ‰ range
Terrestrial C_3 Plants	-27	-35 to -21	3	-8 to 18
Terrestrial C_4 Plants	-13	-14 to -10	3	-8 to 18
Terrestrial Legumes	-27	-35 to -21	1	-7 to 7
Marine Plants	-19	-29 to -8	7	3 to 11
Marine Legumes (cyanobacteria)	-13	-22 to -3	0	-3 to 4
Soil	Same as the plant being supported.	Same as the plant being supported.	9	2 to 12

Compiled from Shearer et al 1978, DeNiro 1987, and Kelly 2000.

Stable isotopes of nitrogen can also be used to investigate agricultural methods, primarily fertilizing practices. A productive field is one that has a source of nitrogen for plant growth. Legumes with bacteria symbiosis have the ability to fix atmospheric nitrogen; most other plants depend entirely on the available nitrogen in the soil in forms of ammonia and nitrate. Fields that grew legumes will have different $\delta^{15}N$ values than those with plants that get their nitrogen strictly from the soil.

Stable isotope analysis of soil can determine the origin of ancient anthropogenic soil deposits. Results from stable carbon and nitrogen isotope analysis provide information regarding the origin of the organic soil constituents, which can be indicators of plant type and infield management. Stable carbon and nitrogen isotopes are used to indicate the origin of the principal organic materials applied to the soil area. Therefore, the stable carbon and nitrogen isotope analysis of infield soils from GUS and Háls can determine the stable carbon and nitrogen composition of soil inputs. This method of stable isotope analysis has been employed successfully in the identification of soils fertilized with seaweed in Orkney (Ambers 1994) Stable isotope analysis has also been employed in the analysis of plant communities that develop over the remains of archaeological sites (Commisso 2002).

The translocation of nitrogen in the soil can affect the isotopic ratios of the soil. The lighter nitrogen isotopes will be the first to undergo mineralization to an inorganic form, which, being more soluble, is more susceptible to leaching, concentrating the heavy isotopes in the soil. Leaching of the lighter isotopes will be kept at a minimum if the soil has been quickly buried under approximately a meter of alluvium. Temperature, soil pH, water, the supply of organic matter (Hauck 1973) and the carbonate content of soil (Len Wassenaar, Environment Canada, personal communication 2000) can also affect the stable isotope ratios of the soil.

CHAPTER 5: STUDY SITES: GUS AND HÁLS

5.1 THE GUS STUDY AREA, GREENLAND

The Gården Under Sandet (GUS) farm was discovered in 1990 by two hunters in search of caribou. The site was eroding out of a riverbank located in the Western Settlement area, West Greenland (50°04'W, 64°06'N, 130 m a.s.l.) about 80 km due east of Nuuk (Berglund 1998) (Figure 5.1).

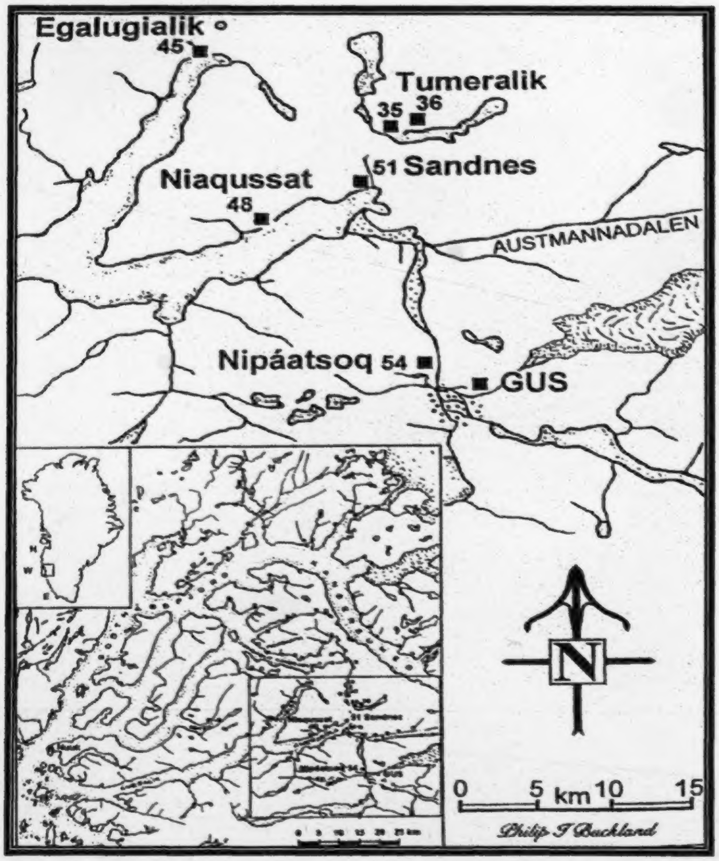
Egalugialik
45
Tumeralik
35
36
51 Sandnes
Niaqussat
48
AUSTMANNADALEN
Nipáatsoq 54
GUS
N
0
5
km
10
15
Philip T Buckland

Figure 5.1: Location of the GUS study area (after Buckland in McGovern et al 1996).

GUS is buried beneath sandy alluvium, north of an outwash plain, which is dissected by glacial meltwater streams from the Kangaassarssup Sermia Valley glacier. Low mountains that rise about 700 to 900 meters a.s.l. surround the site (Berglund 1998; Schweger 1998) (Figures 5.2 and 5.3). The cultural layer is found approximately 150 cm underneath sand and gravel; hence, the site was given the name Gården Under Sandet (the Farm Beneath the Sand) (Berglund 1998). At this depth the site is frozen into the permafrost.

The oldest building on the site was the hall, constructed in the style typical of the Scandinavian longhouse and used between A.D. 1020 and A.D. 1200 (Albrethsen and Ólafsson 1998). This early hall burned and a centralized farm was built over it. The buildings were constructed of walls composed of turf blocks reinforced with stone (Berglund 1998). Radiocarbon dates suggest that GUS was settled around A.D. 1000 (Arneborg 1998) and occupied for 300 years, between the 11th and 14th century (Berglund 1995, 1996). GUS was not a large farm, and was not occupied by the Norse elite. In 1992, excavations were initiated by the Greenlandic National Museum and Archives, and the Danish National Museum during four-week periods over the following five years. Summer excavations ceased when the site was flooded by rising meltwaters from the up-valley glacier. River erosion may now have completely eroded the site away.

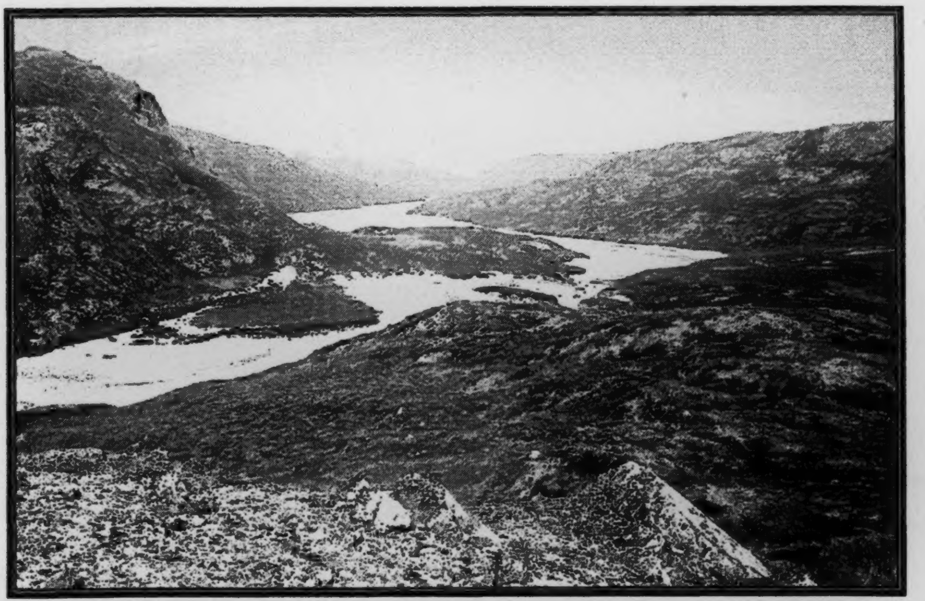

Figure 5.2: The view of the area around GUS, facing north looking down the fjord.

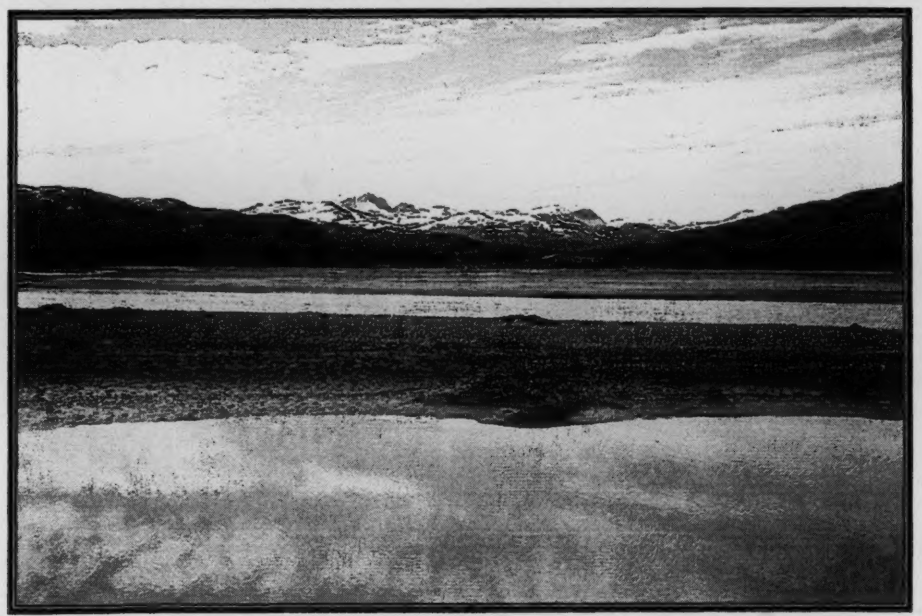

Figure 5.3: The view of the area around GUS, looking upstream. GUS would be just off the left side of the picture. (Photographs taken by Dr. C. Schweger).

5.1.1 Stratigraphy of GUS, Greenland

The geoarchaeological stratigraphy of the GUS site has been published by Schweger (1998). Norse settlers located their farm on a stable Holocene terrace. The development of this farm resulted in an anthropogenic soil. The anthropogenic soil, which is believed to be the infield soil at GUS, ranges in thickness from 6 cm where seen furthest from the buildings to 70 cm adjacent to the buildings (Schweger 1998). Shortly after being abandoned the farm was buried beneath river alluvium that formed a well-marked terrace. The history of GUS is recognized in nine stratigraphic units (Figure 5.4 and Table 5.1).

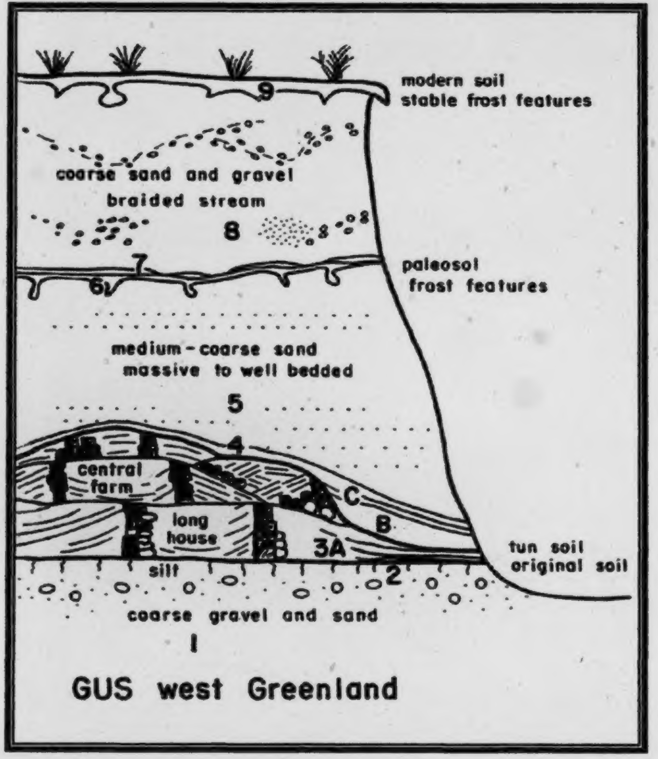
modern soil
stable frost features
9
coarse sand and gravel
braided stream
8
7
6
paleosol
frost features
medium-coarse sand
massive to well bedded
5
4
central farm
C
long house
B
3A
tun soil
original soil
silt
2
coarse gravel and sand
1
GUS west Greenland

Figure 5.4: Generalized geoarchaeological stratigraphy of GUS. Nine stratigraphic units are recognized. Units 3A, 3B, and 3C are the anthropogenic soil, the focus of this thesis. Unit descriptions are presented in Table 5.1 (Schweger 1998).

Table 5.1: Summary of stratigraphic units as per Schweger (1998)

Unit	Description
Unit 9	2 to 5 cm thick, silty organic sand; Ah horizon of the modern soil. Lower contact is transitional over 1-2 cm.
Unit 8	78 to 118 cm thick, coarse sand, gravel, and cobbles. Trough and cross bedding present indicating renewed floodplain aggradation by braided steams. Lower contact is sharp, at places erosional.
Unit 7	2 cm thick, silty fine sand. Lower contact sharp.
Unit 6	5 cm thick, silty organic sand with soil development. Displays cryoturbation, frost crack polygons, infillings and iron staining and may be loessal in origin. The lower contact transitional over 2 cm.
Unit 5	25 to 135 cm thick, sand to pea-gravel and fine to medium sand. Sand and pea gravel exhibits cross bedding. Fine to medium sand is weakly bedded. Contact is sharp at the Unit 5 and Unit 4.
Unit 4	25 cm thick, silty fine sand to medium sand, exhibits well-developed bedding. The sediment was deposited as alluvium over the entire site of GUS. The contact between Unit 4 and Unit 3C is sharp, but not erosional.
Unit 3	10 to 70 cm thick, peat divided into three subunits.
Subunit C	Autochthonous peat, no cultural debris. Formed after the farm was abandoned.
Subunit B	Well preserved autochthonous and allochthonous peat with cultural debris formed during occupation.
Subunit A	Fully decomposed peat with cultural debris, charcoal, sheep dung, and bone, formed during occupation.
Unit 2	10 to 30 cm thick, silt and silty fine sand with some pea gravel near the base. Long period of stability as evidenced by the development of a palaeosol. Exhibits frost cracking and bioturbation. Lenses of charcoal occur in the top layers of this Unit and mark the settlement event. There is a sharp contact between Unit 2 and the overlying Unit 3.
Unit 1	Coarse sand, pea gravel and cobbles composed of mafic rich weathered rocks. No bedding present. This stratigraphic unit is probably of glacial outwash or glacial marine origin. The area of contact between Unit 1 and the overlying Unit 2 is transitional over 5 cm.

5.2 STUDY AREA, HÁLS, ICELAND

The archaeological site of Háls is located at 64°40'49"N, 21°05'24"W in Hálsaveit, Birgarfjanðansýsla, SW Iceland (site reference number 3509/10, National Museum of Iceland) (Figure 5.5).

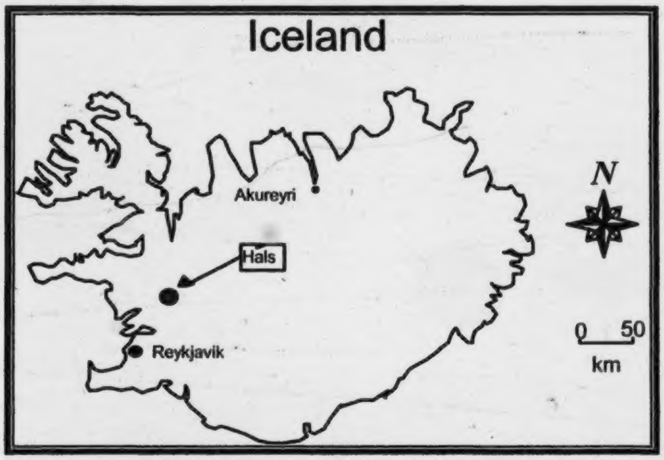

Figure 5.5: Location of the study area, Háls, within Iceland.

Háls, a relatively small and poor farm, was occupied during the medieval Viking period. Háls is mentioned by name in A.D. 1258 in an historical document. But by A.D. 1708 the farm buildings are described as abandoned and in ruins, and the land used by a local farmer (Smith 1989). Háls, which means throat in Icelandic, is located at the southern end of a narrow south-trending ridge. Presently, the area forms a neck in the northeastern corner of property belonging to the Kollaskaekur farm (Smith 1991a). Three sides of the site are sedge peat bogs. Remnants of the tun (infield) wall demarcate the extent of the infield and enclose the ruins of four buildings (Figure 5.6).

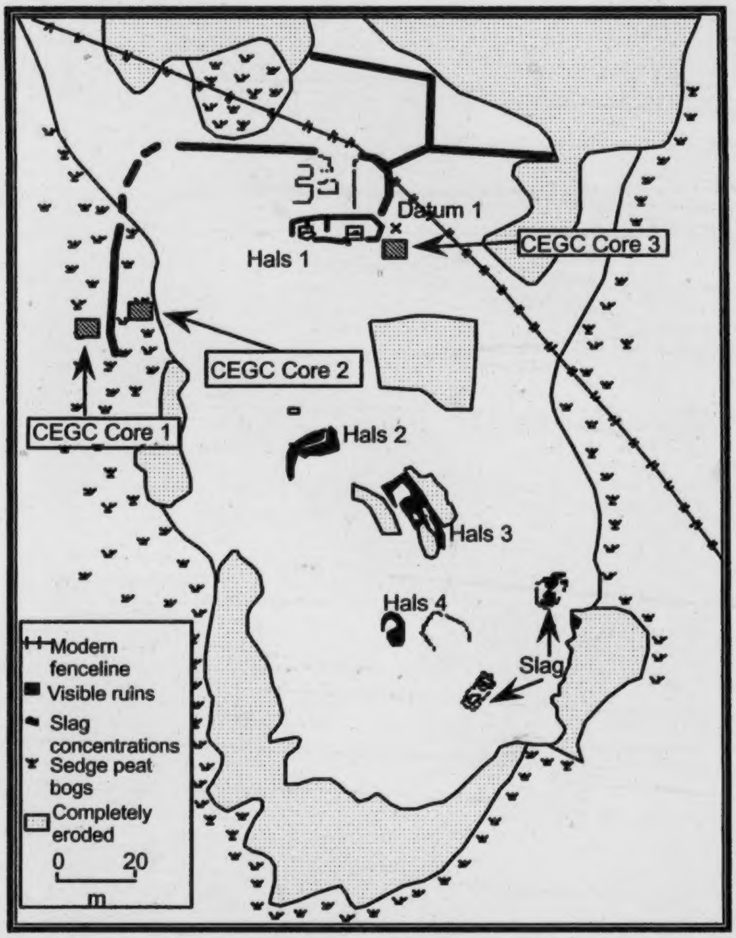
Datum 1
CEGC Core 3
Hals 1
CEGC Core 2
CEGC Core 1
Hals 2
Hals 3
Hals 4
Slag
Modern fenceline
Visible ruins
Slag concentrations
Sedge peat bogs
Completely eroded
0
20
m

Figure 5.6: Site map of Háls showing the location of the three cores used in this study (after Smith 1991b).

The main residential ruin has gone through at least six building phases. Phase 1 represents non-residential use of the site during the Viking age. This phase is characterized by either land clearance or charcoal production. Háls was not only used as a farm, but as a smithy, which produced iron, as large deposits of slag were found at the site. Phases 2 and 3 represents occupation during the medieval period from A.D., 950-1275. Phase 2 is a typical Viking period bow-walled house. During Phase 3, the Phase 2 structure was expanded and partitioned, perhaps to provide stalls for cattle. Phase 4, A.D.

1275-1350, reflects the use of the then abandoned house as an animal shelter. Iron production was the main activity over the century after settlement of Iceland (Smith 1991a). Smith (1991a) concluded that agriculture followed the iron production stage.

5.2.1 Stratigraphy of Háls, Iceland

Smith recognized six stratigraphic units within the site area (Table 5.2).

Table 5.2: General description of stratigraphic units at the Háls site (Smith 1997)

Unit	Description
Unit 1	Ground surface, 6-12 cm, organic silt with abundant roots, charcoal and minute fragments of burnt bone. Lower contact sharp with evidence of cryoturbation.
Unit 2	2-17 cm, medium silt with fewer roots than the overlying layer. Small lenses of the landnam tephra are visible with some burnt bone and charcoal. Small, rounded gravel inclusions present at the base. The lower contact is more transitional than the upper contact.
Unit 3	Discontinuous tephra.
Unit 4	6-18 cm, sandy silt, inclusions of small rounded gravel. No cultural debris present.
Unit 5	Discontinuous silt with inclusions of well-sorted pea gravel. Unit 5 is thrust up into Unit 4. The upper and lower contact is unconformable, probably a result of frost heaving. No cultural debris observed.
Unit 6	>1cm, medium sandy-silt layer mixed with pea gravel. This unit is uniform across the site. No cultural debris present. This Unit is probably glacial in origin.

CHAPTER 6: METHODS AND PROCEDURES

Fourteen cores of anthropogenic soil were collected from the two archaeological sites in Greenland and Iceland. These cores were taken at GUS during the 1995 and 1996 field seasons by C. Schweger, and at Háls in the 2000 field season by the author. At GUS, five cores, collected in four-inch interior diameter PVC pipe that was hammered through the sediment, were taken of Units 2, 3, and 4 associated with site occupation (Figure 5.4 and 6.1). The cores were stored in the freezer and sawed in half for sampling. All depths from the GUS cores are measured from the top of the core barrel. Samples of seaweed, modern dung, and archaeological dung were obtained for comparative analysis of stable isotope data.

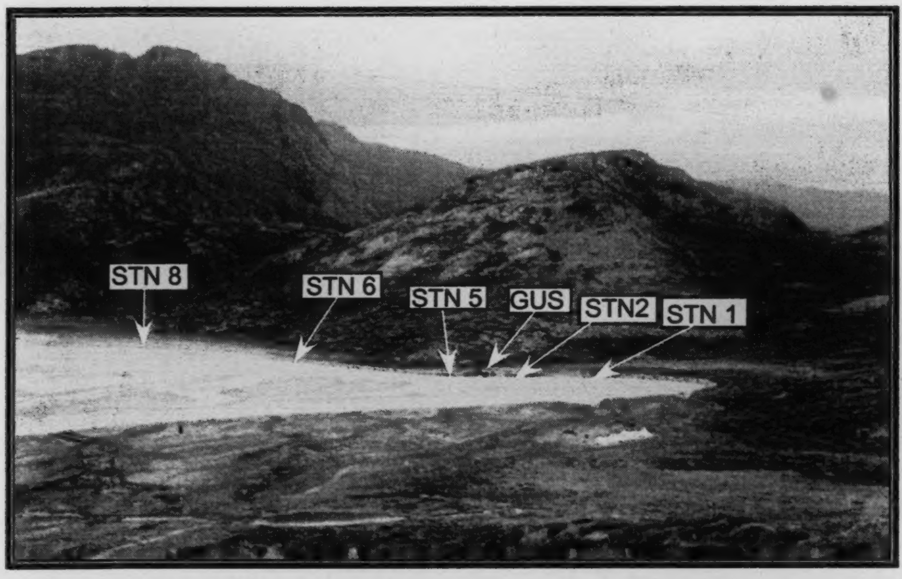

Figure 6.1: Photo of GUS showing the locations of the five cores used in this study.

In Iceland, three cores came from the Háls site in the Borgarfjörður Valley (Figure 5.5). Unlike GUS, the Háls site cores are of a surface soil formed during occupation of the farm site, and all depths are measure below surface. Soils from both sites were chemically analyzed for total carbon, nitrogen, phosphorus, CEC, pH, and stable isotopes of carbon and nitrogen.

Descriptions of the anthropogenic sections at GUS were completed in the field by C. Schweger and in the lab by C. Schweger and C. Fox (Agriculture and Agri-Food Canada). Descriptions of the anthropogenic sections at Háls were completed by the author.

6.1 GENERAL PREPARATION

Each soil core was divided into horizontal sections that were sampled to provide at least 10 grams of dry weight. One centimeter of sediment was sampled every 4 cm from the GUS cores. The Háls cores were divided into 5 cm sample increments. The samples were first dried in an oven at 50°C then sieved through a 2 mm mesh screen to remove rocks, pebbles or larger debris. The screened material was weighed and treated with a 10% HCl solution to remove any carbonates. A ball-mill grinder reduced a small portion of each soil sample to the consistency of fine powder, required for the stable isotope, total N, C, and P analyses.

6.2 STABLE ISOTOPES

Eighty-nine sediment samples from the cores from GUS and Háls, two seaweed samples and four dung samples were processed through a continuous flow Mass Spectrometer, at the University of Saskatchewan, Department of Soil Science, Mass Spectrometry Lab. A small amount of the sample (up to 10 mg) was measured into a tin cup, excess air was squeezed from the tin cup as it was folded to seal the sample inside. Sealed samples were placed into a sample tray interspersed with control samples and then both were analyzed by the mass spectrometer. Precision obtained was ±0.2‰.

6.3 TOTAL CARBON

The total carbon of each sample was determined using the dry combustion method with a Leco-12, Carbon Analyzer at the Natural Resources Analytical Laboratory, Department of Renewable Resources, University of Alberta. With this method the carbon of each sample is oxidized, then the CO_2 gas is measured by an infrared detector, and the total carbon content is presented as a percentage of the initial weight.

6.4 TOTAL NITROGEN AND PHOSPHORUS

Total phosphorus was measured as phosphate because soil phosphorus "…occurs almost exclusively in the phosphate form because of the strong affinity of the element P for oxygen."(Eidt 1984:27). The other forms of phosphorus that occur in soil organic matter are nucleic acids, and phospholipids (Brady and Weil 2000). Schlezinger and Howes (2000) argue that inorganic phosphate and total phosphorus, while a good measure of horizontal distribution of human occupation areas, is unreliable for determining vertical limits of human occupation in a soil section (Schlezinger and Howes 2000). Inorganic phosphorus is subject to some vertical translocation in the soil, but organic phosphorus better reflects the depth of original deposition. Schlezinger and Howes (2000) demonstrated that the anthrosol organic phosphorus concentrations made up the majority of the total phosphorus concentrations. However, at GUS the translocation of inorganic phosphorus within the soil is minimal because after burial beneath alluvium the soil was locked in permafrost.

Total nitrogen and phosphorus were determined using the Kjeldahl method (Page 1982). Sample preparation and analysis was done at the Natural Resources Analytical Laboratory, Department of Renewable Resources, University of Alberta. The samples are measured on an automated continuous flow analyzer. The total nitrogen and phosphorus concentrations are presented as a percentage of the initial weight.

6.5 CATION EXCHANGE CAPACITY

The CEC was determined using the standard ammonium acetate method used by the Natural Resources Analytical Laboratory, Department of Renewable Resources, University of Alberta. A neutral ammonium acetate (NH_4OAc) solution leaches the exchangeable cations from the soil sample. The exchangeable cations are determined using an Atomic Absoption Spectometer and presented as milli-equivalants (me/100g). The ammonium acetate method is advantageous over the other (neutral NaCl) method because this method allows for exchangeable Na^+ to be determined. .

6.6 pH

Sample pH was determined in the Natural Resources Analytical Laboratory, Department of Renewable Resources, University of Alberta. Five or 10 grams of the soil was mixed with 50 ml of de-ionized water and allowed to stand for one half hour and then stirred and measured using a pH meter. The pH was determined for Háls and for Unit 3 at GUS. There was insufficient sample from Units 2 or 4 to determine pH.

CHAPTER 7: RESULTS

7.1 ANALYSES OF THE GUS SEDIMENT CORES

Raw data and profiles are presented as Appendix II and Appendix III. All cores are described with 0 cm at the top. All Munsel colours are determined for wet samples.

7.1.1 Stratigraphy of the Soil Cores from GUS

SCH 6.26.95.1 STN 1

Core SCH 6.26.95.1 STN 1 is 32 cm long. Unit 4 makes up the top 8 cm of the core. Unit 3 makes up the rest of the core from 8 to 32 cm (Table 7.1).

Table 7.1: SCH 6.26.95.1 STN 1

Unit as defined by C. Schweger	Depth (cm)	Description
Unit 4	0-8	Silty fine sand, light grey, some horizontal lenses of peat. Preserved rootlets. Lower contact sharp.
Unit 3	8-15	Horizontally bedded peat with some silt, very dark grey. Peat is more fibrous. No cultural debris.
	15-20	Horizontal silt lenses interspersed with felted, bedded peat.
	20-28	Horizontally bedded felted peat with some silt, very dark grey. Charcoal present.
	28-32	Sandy silt, high in organic matter. Fibrous peat horizons. Crumbles apart. Grey.

SCH 7.1.95.1 STN 2

Core SCH 7.1.95.1 STN 2 is 44 cm long. Unit 4 makes up the top 15 cm. Unit 3 makes up the rest of the core from 15 to 44 cm (Table 7.2).

Table 7.2: SCH 7.1.95.1 STN 2

Unit as defined by C. Schweger	Depth (cm)	Description
Unit 4	0-15	Silty fine sand with lenses of organic matter occurring in the bottom half. Rootlets are visible in the top half. Bedding is irregular and wavy. Light grey colour. Lower contact is sharp.
Unit 3	15-17	Autochthonous peat (Dr. C. Schweger, University of Alberta, personal communication). Well-preserved organics. Higher concentration of silt than the lower layer. Lighter in colour than the lower layer.
	17-32	Autochthonous peat (Dr. C. Schweger, University of Alberta, personal communication). Peat peels apart. Well-decomposed although some organics are well preserved. Darker than the lower layer. Includes inclusions of silt less than 0.5 cm thick. Cultural debris present (charcoal and bone). Salty smell. (Dr. C. Fox, Agriculture and Agri-Food Canada, personal communication)
	32-44	Autochthonous peat (Dr. C. Schweger, University of Alberta, personal communication) Well-decomposed felted layers of peat that peel apart. Silt increases with depth. Colour lightens downwards. Cultural debris present (charcoal and bone)

SCH24.6.96.1 STN 5

Core SCH 7.1.96.1 STN 5 is 76 cm long. Unit 4 makes up the top 14 cm. Unit 3 is present between 14 and 71 cm. Unit 2 makes up the bottom 5 cm from 71 to 76 cm (Table 7.3).

Table 7.3: SCH24.6.96.1 STN 5

Unit as defined by C. Schweger	Depth (cm)	Description
Unit 4	0-14	Grey sediment (10 YR 5/1) grading from clay to fine silt to sand. Friable, and rootlets are present. Lower contact is sharp.
Unit 3	14-37	Horizontally layered peat. Contains fine sand and silt. Well-preserved organics in the top half well decomposed in the bottom half. Peels apart. Cultural debris present (sheep and cow dung, charcoal, bone, and shell) Rare mineral grains present (Dr. C. Fox, Agriculture and Agri-Food Canada, personal communication) Colour 10 YR 2/2 dark brown.
	37-71	Horizontally layered peat. More silt present in this layer than the above layer. Cultural debris present (sheep dung, charcoal and bone). Colour is 10 YR 3/2 very dark grey. Lower contact is sharp.
Unit 2	71-76	Fine silt and sand. Very little organics are present. No cultural debris. Colour is 10 YR 6/2 light brownish grey.

SCH 23.6.96.7b STN 6

Core SCH 7.1.96.7b STN 6 is 45 cm long. Unit 4 is present in the top 5 cm. Unit 3 is present between 5 and 26 cm. Unit 2 is present in the bottom 19 cm from 26 to 45 cm (Table 7.4).

Table 7.4: SCH 23.6.96.7b STN 6

Unit as defined by C. Schweger	Depth (cm)	Description
Unit 4	0-1	Very fine silt.
	1-5	Particle size increases downward from fine silt to sand. Intermixed with lenses of organic matter. Colour is 10 YR 6/1 Grey.
Unit 3	5-22	Horizontally layered well-decomposed peat. Peels apart. Contains silt particles. Possible animal manure (Dr. C. Fox, Agriculture and Agri-Food Canada, personal communication).
	22-26	Coarse to medium grain sand. Colour is 10 YR 7/3 very pale brown to 2.5Y 3.5/2, dark greyish yellow (Dr. C. Fox, Agriculture and Agri-Food Canada, personal communication). Upper and lower contact is sharp.
Unit 2	26-29	Palaeosol (Dr. C. Fox, Agriculture and Agri-Food Canada, personal communication). Colour is 10YR 4/2 black. Highly organic.
	29-45	Silt grades finer with depth. Dark greyish brown. Yellows with depth to brown.

SCH 23.6.96.7 STN 8

Core SCH 7.1.96.7 STN 8 is 14 cm long. Unit 4 is present in the top 3 cm. Unit 3 is present between 3 and 11 cm. Unit 2 makes up the bottom 3 cm from 11 to 14 cm (Table 7.5).

Table 7.5: SCH 23.6.96.7 STN 8

Unit as defined by C. Schweger	Depth (cm)	Description
Unit 4	0-3	On the left side of the core a portion of unit 4 is intact. It is composed of coarse sand and silt. There is a sharp non-horizontal lower contact.
Unit 3	3-11	Peat and silt. Roots several centimeters long are distinguishable. Very fibrous and peels apart, but otherwise is well decomposed. Horizontal layering. Dark greyish brown, lower contact transitional
Unit 2	11-14	Silt with an Ah Horizon. Charcoal is present at the upper boundary. Dark greyish brown.

7.1.2 STN 1

Results are presented in Figure 7.1.

Phosphorus results of Unit 3 vary from 0.11 to 0.26% and peak between 18 and 26 cm. The phosphorus results are lower in Unit 4 (0.09%), than in Unit 3.

The carbon results of Unit 3 range from 6.93 to 22.4% and the carbon concentration decreases with depth. The carbon content of Unit 4 (12.9%) is approximately half the carbon content of the top of Unit 3 (22.4%).

The nitrogen results of Unit 3 range from 0.51 to 1.67% and the nitrogen content of Unit 3 decreases with depth. The nitrogen content of Unit 4 (0.91%) is approximately half of the nitrogen content of the top of Unit 3 (1.67%).

The C:N ratios of Unit 3 range from 12:1 to 15:1, but have a mean value of 11:1. The C:N ratio of Unit 4 is 14:1.

The CEC results from Unit 3 range from 29.55 to 61.97 me/100g. The CEC of Unit 3 decreases with depth. The CEC of Unit 4 (30.45 me/100g) is half the CEC of the top sample from Unit 3 (69.85).

The $\delta^{13}C$ results of Unit 3 range from –27.69 to –26.6‰ and show only a 1‰ increase in heavier isotopes with respect to depth in Unit 3. The $\delta^{13}C$ results are generally stable around –27.2‰. The $\delta^{13}C$ result of Unit 4 is –26.58‰. There is very little difference between the $\delta^{13}C$ results of Unit 3 and Unit 4. The $\delta^{15}N$ results of Unit 3 range from 4.46 to 8.05‰, and exhibit an overall 3.5‰ increase in lighter isotopes with respect to depth. The $\delta^{15}N$ result of Unit 4 is 5.17‰.

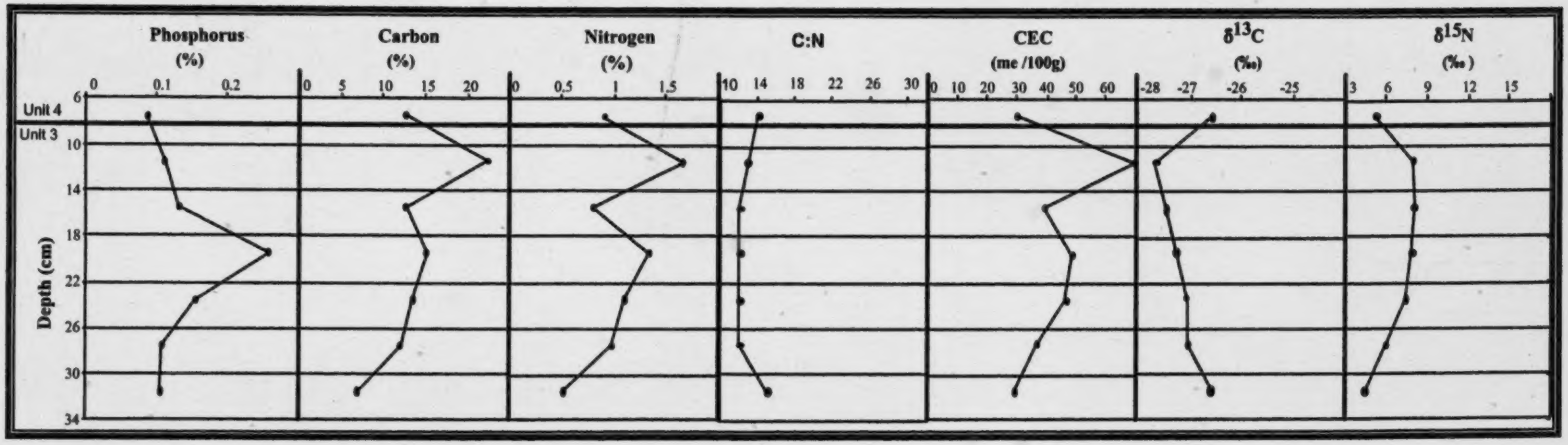

Figure 7.1: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for STN 1.

7.1.3 STN 2

Results are presented in Figure 7.2.

Phosphorus results of Unit 3 vary from 0.07 to 0.26% and peak between 20 and 28 cm. The phosphorus results in Unit 4 are much lower, 0.04 to 0.05%.

The carbon results of Unit 3 range from 10.88 to 22.32%. The carbon concentration of Unit 3 decreases slightly with depth. The carbon content of Unit 4 ranges from 1.55 to 3.23%, much lower than the carbon content of Unit 3.

The nitrogen results of Unit 3 range from 1.28 to 1.89%. The nitrogen content of Unit 3 decreases slightly with depth. The nitrogen content of Unit 4 ranges from 0.06 to 0.15%.

The C:N ratios of Unit 3 range from 11:1 to 13:1, but have a mean value of 12:1. The C:N ratios of Unit 4 range from 12:1 to 31:1.

The CEC results from Unit 3 range from 43.16 to 68.7 me/100g. The CEC of Unit 3 increases slightly with depth. The CEC of Unit 4 ranges from 7.13 to 11.04 me/100g.

The $\delta^{13}C$ results of Unit 3 range from –27.48 to –26.94‰ and show only a 0.5‰ increase in heavier isotopes with respect to depth in Unit 3. The $\delta^{13}C$ results are generally stable around -27‰. The $\delta^{13}C$ results of Unit 4 range from –27.63 to –26.25‰, but have a mean value of –26.33. Unit 4 is more enriched in $\delta^{13}C$ than Unit 3 by about 1‰. The $\delta^{15}N$ results of Unit 3 range from 6.59 to 10.03‰, and become depleted with depth. The $\delta^{15}N$

results of Unit 4 range from 4.66 to 5.58‰, and become slightly enriched with depth. Overall, Unit 3 is enriched by 3.5‰.

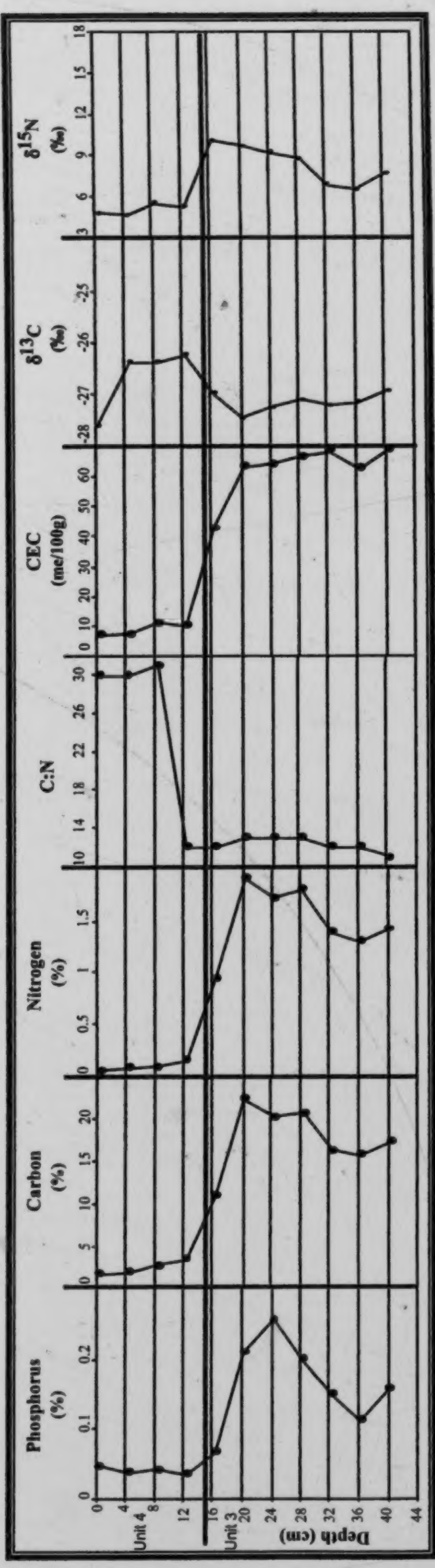

Figure 7.2: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for STN 2.

7.1.4 STN 5

Results are presented in Figure 7.3.

Phosphorus results of Unit 2 are around 0.07%. The phosphorus results of Unit 3 vary from 0.13 to 0.24%, much higher than the phosphorus results from Unit 2. In Unit 3 the phosphorus content increases with depth. The phosphorus results in Unit 4 range from 0.03 to 0.05%.

The carbon results of Unit 2 are 1.1 to 1.7%, and for Unit 3 8.9 to 23.9%. The highest carbon content is in the middle of Unit 3. The carbon content of Unit 4 ranges from 0.7 to 1.3%.

The nitrogen results of Unit 2 range from 0.8 to 0.16%. The nitrogen results of Unit 3 range from 0.73 to 1.8%. The nitrogen content of Unit 3 decreases with depth. The nitrogen content of Unit 4 ranges from 0.06 to 0.09%. The nitrogen content parallels that of carbon.

The C:N ratios of Unit 2 range from 11:1 to 15:1. The C:N ratios of Unit 3 range from 11:1 to 16:1 but have a mean value of 13:1. The C:N ratios of Unit 4 range from 15:1 to 19:1.

The CEC results from Unit 2 range from 8.7 to 18.1 me/100g. The CEC results of Unit 3 range from 31.2 to 64.2 me/100g and are much higher than the CEC results from Unit 2. The CEC of Unit 3 is generally constant throughout this Unit. The CEC of Unit 4 ranges from 2.2 to 4.4 me/100g.

The $\delta^{13}C$ results of Unit 2 are around –26‰. The $\delta^{13}C$ results of Unit 3 range from –27.2 to –26.7‰ and have a mean value of -27‰. The $\delta^{13}C$ results of Unit 4 range from –27.5 to –24.8‰. The $\delta^{13}C$ results vary by 2‰ across Units 2, 3, and 4. The $\delta^{15}N$ results of Unit 2 range from 5.8 to 6.5‰. The $\delta^{15}N$ results of Unit 3 range from 3.4 to 8.9‰, but have a mean value of 8‰. The $\delta^{15}N$ results of Unit 4 range from 5.0 to 8.4. Overall, Unit 3 is enriched in $\delta^{15}N$ compared to Units 2, and 4.

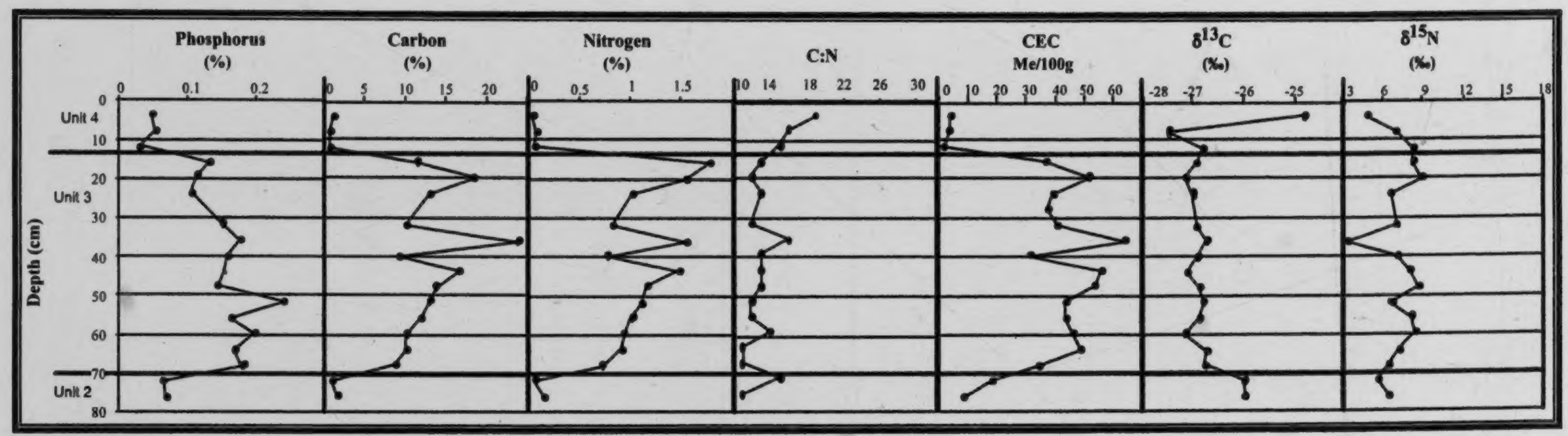

Figure 7.3: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for STN 5.

7.1.5 STN 6

Results are presented in Figure 7.4.

Phosphorus results of Unit 2 range from 0.07 to 0.12%. The phosphorus results of Unit 3 vary from 0.06 to 0.21% and are higher than the phosphorus results from Unit 2. In Unit 3 the phosphorus content decreases with depth. The phosphorus results in Unit 4 have a mean value of 0.04%.

The carbon results of Unit 2 range are from 1.1 to 5.7%. The carbon results of Unit 3 range from 1.0 to 19.6% and are higher than the carbon results from Unit 2. The carbon content decreases with depth in Unit 3. The carbon content of Unit 4 ranges from 0.8 to 1.1%.

The nitrogen results of Unit 2 range from 0.09 to 0.37%. The nitrogen results of Unit 3 range from 0.1 to 1.5%. The nitrogen content of Unit 3 decreases with depth. The nitrogen content of Unit 4 ranges from 0.05 to 0.09%. The nitrogen content parallels that of carbon.

The C:N ratios of Unit 2 range from 13:1 to 22:1. The C:N ratios of Unit 3 range from 11:1 to 16:1 but have a mean value of 14:1. The C:N ratios of Unit 4 range from 13:1 to 15:1.

The CEC results from Unit 2 range from 8.3 to 26.3 me/100g, and generally decrease with depth. The CEC results of Unit 3 range from 6.2 to 65.1 me/100g are higher than the CEC results of Unit 2, and generally decrease with depth. The CEC of Unit 4 ranges from 2.5 to 4.2 me/100g and is lower than the CEC for Unit 3 or Unit 2.

The $\delta^{13}C$ results of Unit 2 range from –26.8 to –25.9‰. The $\delta^{13}C$ results of Unit 3 range from –26.9to –26.2 and have a mean value around –26.5‰. The $\delta^{13}C$ results of Unit 4 range from –26.5 to –26.0‰. The $\delta^{13}C$ results do not vary by much from Unit 2, Unit 3, or Unit 4. The $\delta^{15}N$ results of Unit 2 range from 6.0 to 6.9‰. The $\delta^{15}N$ results of Unit 3 range from 7.8 to 9.1‰ and are more enriched in ^{15}N than Unit 2, and generally decrease with depth. The $\delta^{15}N$ results of Unit 4 range from 6.9 to 9.2.

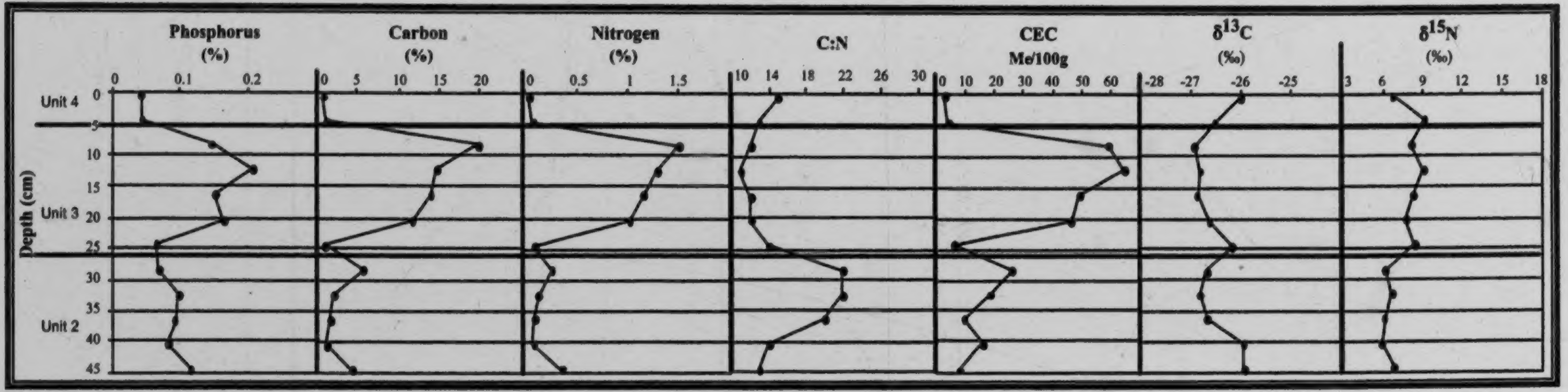

Figure 7.4: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for STN 6.

7.1.6 STN 8

Results are presented in Figure 7.5.

The phosphorus content from Unit 2 is 0.08%. The phosphorus results of Unit 3 vary from 0.08 to 0.10%. The phosphorus content of Unit 4 is 0.05%.

The carbon content of Unit 2 is 4.5%. The carbon results of Unit 3 are around 9.6%. The carbon content of Unit 4 is 3.0%.

The nitrogen content of Unit 2 is 0.23%. The nitrogen results of Unit 3 range from 0.78 to 0.97%. The nitrogen content of Unit 4 is 0.25% and is similar to the nitrogen content of Unit 2. The nitrogen content parallels that of carbon.

The C:N ratio of Unit 4 is 21:1. The C:N ratios of Unit 3 range from 11:1 to 12:1. The C:N ratio of Unit 4 is 14:1.

The CEC result from Unit 2 is 17.44 me/100g. The CEC results of Unit 3 range from 35.47 to 38.97 me/100g and are higher than the CEC of Unit 2. The CEC of Unit 4 is 13.47 me/100g.

The δ^{13}C result of Unit 2 is –26.6‰. The δ^{13}C results of Unit 3 have a mean value around –26.3‰. The δ^{13}C result of Unit 4 is –26.2‰. The δ^{13}C results do not vary much from Unit 2, Unit 3, and Unit 4. The δ^{15}N result of Unit 2 is 16.5‰. The δ^{15}N results of Unit 3 range from 9.7 to 11‰ and are depleted in δ^{15}N compared to Unit 2. The δ^{15}N result of Unit 4 is 8.3‰ and is the more depleted in δ^{15}N than Unit 2 and Unit 3.

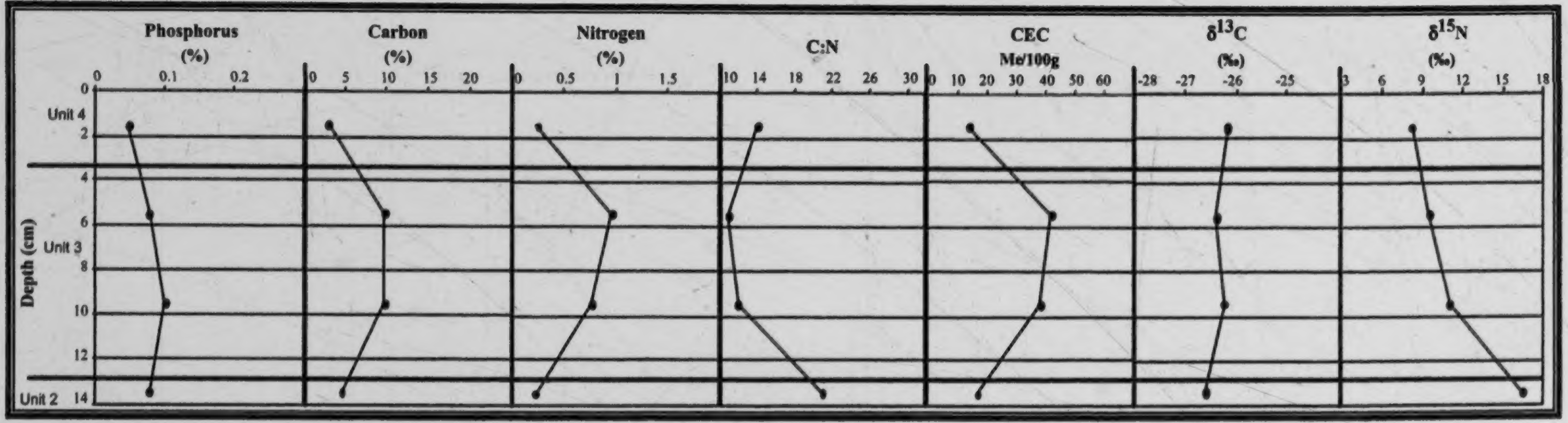

Figure 7.5: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for STN 8.

7.2 SUMMARY OF RESULTS OF GREENLAND CORES

7.2.1 Phosphorus Results

Phosphorus results range from a minimum of 0.05% in Unit 4 at STN 2 (0-1 cm) to a maximum of 0.26% in Unit 3 at STN 1 (19-20 cm). There is some variability among the cores. These results strongly correlate with the stratigraphic units in each core. Unit 3, the anthropogenic sediment, contains the highest phosphorus content, an average of 0.15%. Unit 2 with an average of 0.08% has about half the phosphorus content of Unit 3. Unit 4 made up of unweathered sediment with no cultural debris has the least amount of phosphorus, with an average of 0.04%.

7.2.2 Carbon Results

Carbon results range from a minimum of 0.72% in Unit 4 at STN 5 (11-12 cm) to a maximum of 23.91% in Unit 3 at STN 5 (35-36 cm). These results strongly correlate with the stratigraphic units of each core. The anthropogenic sediment, Unit 3, has the highest carbon content with an average of 14.34%. Unit 2, the pre-settlement sediment, has an average of 3.87% carbon, about a third of that of Unit 3. Unit 4, the alluvial sediment has the least amount of carbon, with an average of 1.38%.

7.2.3 Nitrogen Results.

Nitrogen results range from a minimum of 0.05% in Unit 4 at STN 6 (0-01 cm) to a maximum of 1.89% in Unit 3 at STN2 (20-21 cm). Like phosphorus and carbon, the percent nitrogen strongly correlates with the stratigraphic units in each core. There is a close parallelism depth by depth between carbon and nitrogen. Unit 3, the anthropogenic soil, contains the highest nitrogen content with an average of 1.2%. Unit 2, the pre-settlement sediment, has an average of 0.26%, about a quarter of the Unit 3 nitrogen content. Unit 4, the alluvial deposit, has the least amount of nitrogen with an average of 0.08%.

7.2.4 C/N Ratios

There is a large range in C/N ratios from 31:1 to 11:1 through the five soil cores. Unit 2, the pre-settlement sediment has a C/N ratio, which ranges from a maximum of 22:1 to a minimum of 11:1, but averages 17:1. Unit 3, the anthropogenic soil, has a C/N ratio, which ranges from a maximum of 16:1 to a minimum of 11:1 and averages 12:1. Unit 4, the alluvial sediment has a C/N ratio that ranges from 31:1 to 12:1, but averages 18:1.

7.2.5 pH Results

Table 7.6: pH results from Unit 3 of the GUS samples.

Sample	pH
STN 1	5.65
STN 2	6.00
STN 5	6.21
STN 6	6.23
STN 8	6.02

The soil at GUS is moderately acidic, common of arable soils (Brady and Weil 2000) (Table 7.6). These pH values indicate that there are no carbonates present (Dr J. Robertson, University of Alberta, personal communication 2004). The mineral sediment is slightly acidic because it is a product of the bedrock (granites and gneisses), which is high in silica.

7.2.6 Cation Exchange Capacity Results

The results ranged from a minimum of 2.15 me/100g in Unit 4 at STN 5 (11-12 cm) to a maximum of 69.85 me/100g in Unit 3 at STN 1 (11-12 cm). The values strongly correlate with the stratigraphic units in each core. Unit 3, the anthropogenic soil contains the highest CEC content with an average of 50.9 me/100g. Unit 2, the pre-settlement sediment averages 14.96 me/100g, about a third of the CEC of Unit 3. Unit 4, the alluvial sediment, has the lowest CEC with an average of 7.27 me/100g.

7.2.7 $\delta^{13}C$ Results

The $\delta^{13}C$ results vary from a minimum of -27.69‰ in Unit 3 at STN 1 (11-12 cm) to a maximum of -24.78‰ in Unit 4 at STN 5 (03-04 cm). Most of the results fall between -6.4‰ and -27‰. In cores STN 1, STN 5, STN 6, and STN 8, the $\delta^{13}C$ values do not correlate with the stratigraphic units.

7.2.8 $\delta^{15}N$ Results

The $\delta^{15}N$ results vary from a minimum of 3.42‰ in Unit 3 at STN 5 (35-36 cm) to a maximum of 16.54‰ in Unit 4 at STN 8 (1-2 cm). In cores STN 1, STN 5, STN 6, and STN 8, the $\delta^{15}N$ values do not correlate with the stratigraphic units. There is about a 2‰ difference in the average $\delta^{15}N$ results between Units 2 and 4, and Unit 3. Unit 3 has an average $\delta^{15}N$ result of 8.35‰, whereas Unit 2 and Unit 4 have an average $\delta^{15}N$ result of 6.41‰ and 6.64‰, respectively. However, inter-unit variation is greater than intra-unit variation. Therefore, differences noted between each unit are negligible.

7.2.9 Stable Isotope Comparative Samples

Manure found in association with Norse structures was collected from GUS by C. Schweger and J. Ross. Contemporary sheep dung from Southern Greenland farms and marine plants from the Nuuk coast were also collected. These samples were analyzed for $\delta^{15}N$ and $\delta^{13}C$ content, the results of which are compared with the soil profile stable isotope values (Table 7.7).

Table 7.7: Stable isotope results on organic material.

Sample	Area, Layer	Material	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)
Marine plant 1	Nuuk	Marine plant	-14.9	5.64
Marine plant 2	Nuuk	Marine plant	-14.64	3.57
Modern sheep	Field near Iqualic	Caprine dung	-29.32	3.74
SCH 8.7.96.4	Room 4	Bovine dung	-27.90	2.32
SCH 1.7.96.8 #3158	Layer 35	Dung, unknown type	-27.10	3.28
SCH 6.7.91.1 #3164	Room 25	Caprine dung	-26.61	3.44
GUS cow 3459	Inside?	Bovine dung	-26.89	3.17

Additional information on the $\delta^{13}C$ values of organic artifacts comes from a radiocarbon dating study completed by J. Arneborg (Table 7.8).

Table 7.8: Previous δ^{13}C results from GUS on a variety of material. Unless otherwise stated all animal specimens are from bone (From Arneborg, 2001 and 2003).

Sample	Material	δ13C (‰)
AAR 3396	Twigs	-25.2
K-5824	Charcoal *Salix cf. glauca & Betula nana*	-25.1
K-5825	*Salix cf. glauca*	-26.5
AAR 3393	Twigs	-25.7
AAR 3682	Textile/wool	-22.1
AAR 3681	Animal droppings	-26.7
AAR-1633	Terrestrial bone	-18.4
AAR 3397	Sheep	-20.2
AAR-5406	Sheep	-19.9
AAR-3899	Sheep/goat phalanx	-19.2
K-6017	Sheep/goat	-20.0
AAR-1636	Sheep/goat	-17.4
AAR-1638	Sheep/goat	-19.2
K-6631	Sheep/goat	-19.4
AAR-1637	Sheep/goat	-20.1
AAR-4461	Goat	-19.58
AAR-4291	Goat	-19.5
AAR 3394	Cattle	-20.8
K-6018	Cattle	-20.2
AAR-5400	Cattle	-19.9
AAR-5401	Horse	-21.2
AAR-5405	Horse	-21.0
K-5823	Reindeer antler	-18.8
AAR-3735	Reindeer	-18.1
AAR-3395	Reindeer	-18.8
AAR-2508	Walrus tooth	-12.8
AAR-3900	Seal astragalus	-14.1

7.3 ANALYSES OF THE HÁLS SEDIMENT CORES

Raw data and profiles are presented as Appendix II and Appendix III.

7.3.1 Stratigraphy of the Soil Cores from Háls.

CEGC Core-1, Outfield

This 35 cm long core was taken from a peat bog about 5 m west of the remnants of the tun wall. Ground surface is represented at 0 cm. CEGC Core-1 is located near K. Smith's transect 1, cores 1.8 and 1.9 (Figure 5.5). This core was taken outside of the infield proper and therefore does not correlate with the stratigraphic units described for the site by Kevin Smith (Table 7.9).

Table 7.9: CEGC Core-1

Unit as defined by K. Smith	Depth (cm dbs)	Description
No match	0-95	Homogenous humified peat with small pieces of visible organics, no bedding present, dark brown.

CEGC Core-2, Infield

This core is situated on the western edge of the site about 5 m east of and within the remnants of the tun wall (Figure 5.5). The entire length of this core is 95 cm long. The core was wet throughout when collected and had an unpleasant odour (Table 7.10).

Table 7.10: CEGC Core-2

Unit as defined by K. Smith	Depth (cm dbs)	Description
Unit 1	0-5	Highly organic with the presence of roots from the overlying vegetation mat, black
No match	5-10	Horizontally matted peat, Well humified, dark brown.
	10-17	Very dark brown. Mostly organic. Rust staining present, increase in silt.
	17-50	Horizontally bedded peat with silt increasing downwards, black. Peat is well humified and less matted than the overlying layer.
	50-71	Horizontally bedded peat with less silt than the overlying layer. Well humified and greasy.
	71-90	Inter-layering of horizontally banded peat. Alternating dark and light layers. Well humified with a few exceptions of small twigs.
No match	90-95	A layer of silty sand peat.

CEGC Core-3, Farm

This 60 cm core was taken in the infield about 5 m east of the ruin Háls 1 (figure 5.5) (Table 7.11).

Table 7.11: CEGC Core-3

Unit as defined by K. Smith	Depth (cm dbs)	Description
Unit 1	0-7	Highly organic silt layer consisting of roots from the overlying vegetation mat, very dark brown. Lower contact transitional.
Unit 2	7-58	Homogenous organic silt matrix, dark brown. Bone present between 15-25 cm
No match	58-60	Clay present.

7.3.2 CEGC Core-1, The Outfield

Results are presented in Figure 7.6.

The phosphorus results range from 0.11% at 0-5 cm to 0.17 % at 15-20 cm dbs. These results vary by only 0.06% throughout the entire core with the highest levels of phosphorus occurring in the middle of the core.

Carbon varies between 20 to 30% throughout the core, and nitrogen varies between 1.15 to 1.88% and gradually increases with depth. The C/N ratio ranges from a maximum of 22:1 to a minimum of 14:1, and decreases with depth. The average C: N ratio for the entire profile is 18:1. The total CEC results range from 15.76 me/100g at 0-5 cm dbs to 26.07 me/100g at 30-35 cm dbs. The total CEC gradually increases with depth in Core-1 from 17 me/100g to 26 me/100g. The pH results of Core 1 are 5.7, which indicates that the soil is moderately acidic (Brady and Weil 2000).

The δ^{13} C results range from –29.3‰ to –28.6 ‰, and shows a slight general trend of decreasing δ^{13} C with respect to depth. Core-1 The δ^{15}N results range from a minimum of 0.84‰ at the top to a maximum of 3.15‰ at the base. The mean percent δ^{15}N of Core-1 is 1.65%. Core-1 shows a small increase in δ^{15}N with respect to depth.

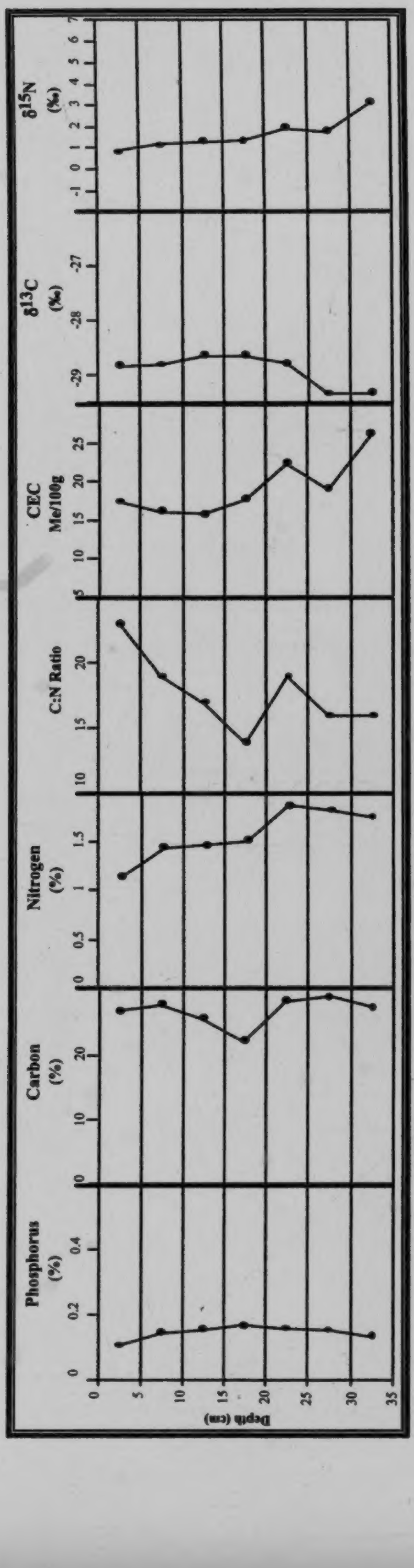

Figure 7.6: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for CEGC Core 1.

7.3.3 CEGC Core-2, The Infield

Results are presented in Figure 7.7.

The phosphorus results range from 0.1% at the base to 0.22% at 55-60 cm dbs. The phosphorus levels of Core-2 show a slight general trend of increasing phosphorus with respect to depth. The very bottom of the profile 85-95 cm dbs is the exception and phosphorus levels are half of the overlying layers.

The carbon results range from 1.57% at the base to 22% at 55-60 cm dbs. There is considerable variation in 0-80 cm dbs. Generally the carbon content decreases with respect to depth. The nitrogen results range from 0.16% at the base 1.55% at 55-60 cm dbs. The nitrogen content follows the same pattern as the carbon content for this core.

The C/N ratios of Core-2 range from 12:1 to 17:1, decreasing with respect to depth. The average C/N ratio for the entire profile is 15:1. The C/N ratios are constant from 10-80 cm dbs. The pH results of Core 2 are 5.8, which indicates that the soil at Háls is moderately acidic (Brady and Weil 2000). The total CEC values in Core-2 are consistent from 20-85 cm dbs ranging from 1.1 me/100g to 4.18 me/100g at the base.

The δ^{13} C results range from –29.3‰ to –28.6 ‰, with an average of -27.8‰. The δ^{13} C values are quite variable, but there is a general trend of increasing δ^{13}C with respect to depth. The δ^{15}N results range from –1.0‰ at 35-40 cm dbs to 4.2‰ at 90-95 cm dbs, with an average of 1.6%.

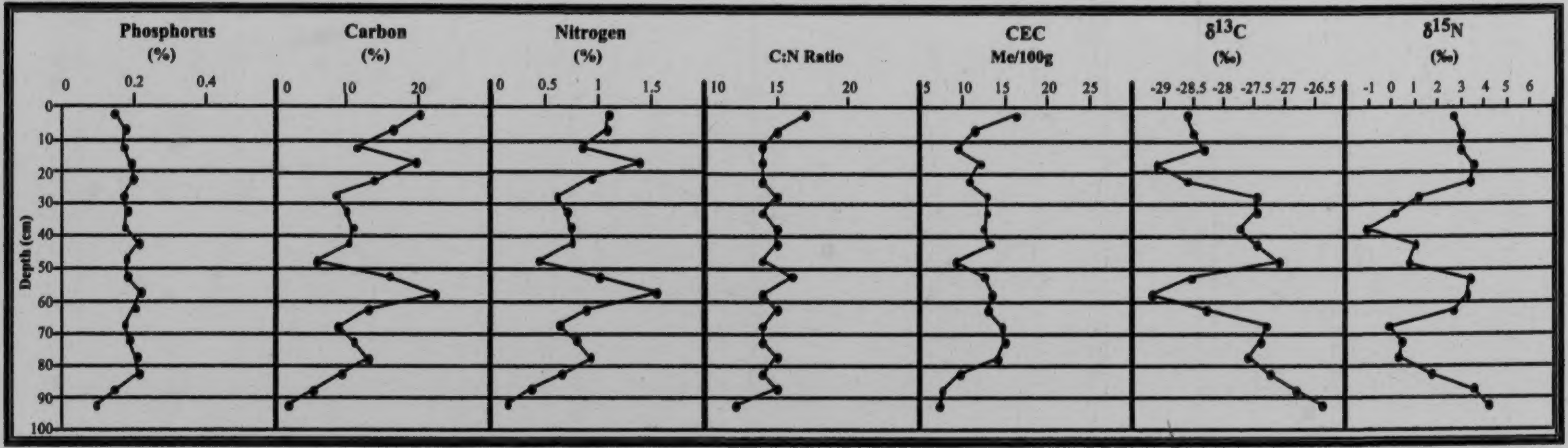

Figure 7.7: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for CEGC Core 2.

7.3.4 CEGC Core-3, Next to The Farm Buildings

Results are presented in Figure 7.8.

The phosphorus results range from 0.25% at 0-5 cm dbs to 0.54 % at 15-20 cm dbs. Two phosphorus peaks occur between 15-30 cm dbs and between 40-50 cm dbs.

The carbon results range from 6.79% at 60-65 cm dbs to 13.83% at 0-5 cm dbs. The nitrogen results range from 0.55% at the base to 1.08% at the top. The carbon and nitrogen results are constant throughout the core with a slight decrease in carbon and nitrogen content with respect to depth. The C/N ratios range from 11:1 to 14:1. The average C/N ratio for the entire profile is 12:1. The pH results of Core 3 are 5.5, which indicates that the soil at Háls is moderately acidic (Brady and Weil 2000).

The CEC results range from 7.65 me/100g at 10-15 cm dbs to 19.75 at 40-45 cm dbs.

The $\delta^{13}C$ results range from –28‰ to –26.6 ‰. The $\delta^{13}C$ results of Core-3 show little variability throughout the column and are constant around –27.2‰, although there is a slight increase in $\delta^{13}C$ with respect to depth. The $\delta^{15}N$ results range from 5.0‰ at 30-35 cm dbs to 6.8‰ at 15-20 cm dbs, with an average of 5.8‰. The $\delta^{15}N$ results are constant with only a slight increase in heavy isotopes with respect to depth.

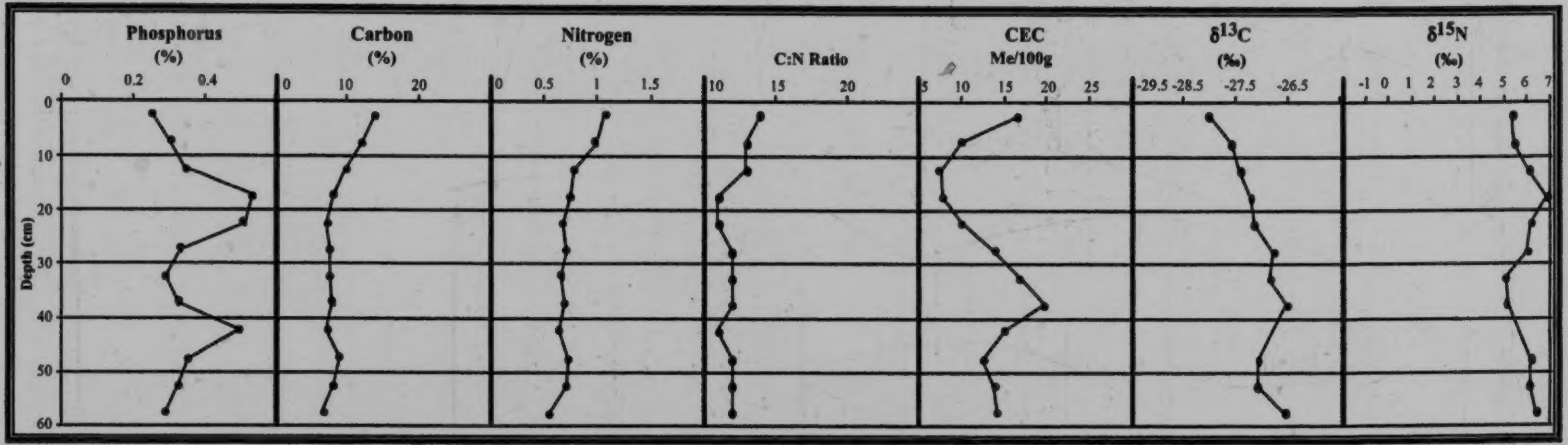

Figure 7.8: Results of phosphorus, carbon, nitrogen, CEC, $\delta^{13}C$ and $\delta^{15}N$ by depth for CEGC Core 3.

7.4 SUMMARY OF RESULTS FOR ICELAND

7.4.1 Phosphorus Results.

The phosphorus results ranged from a minimum of 0.1% at Core 2 (90-95 cm dbs) to a maximum of 0.54% at Core 3 (20-25 cm dbs). Core 1, with an average of 0.15%, has the lowest phosphorus content, while Core 3, with a mean value of 0.4%, has the highest phosphorus content. In Cores 1 and 2 the phosphorus content is constant throughout the core, whereas for Core 3 the phosphorus content peaks at 15-30 and 40-55 cm dbs.

7.4.2 Carbon Results.

The carbon results ranged from a minimum of 1.6% at Core 2 (90-95 cm dbs) to a maximum of 28.8% at Core 1 (25-30 cm dbs). Core 1, with a mean value of 26.6%, has the highest carbon content, while Core 3, with a mean value of 7.8%, has the lowest carbon content.

7.4.3 Nitrogen Results

The nitrogen results ranged from a minimum of 0.16% at Core 2 (90-95 cm dbs) to a maximum of 1.9% at Core 1 (20-25 cm dbs). Core 1, with a mean value of 1.6%, has the highest nitrogen content, while Core 3, with a mean value of 0.7%, has the lowest nitrogen content. The nitrogen content in Core 2 and Core 3 decreases with respect to depth, while in Core 1 it increases slightly with respect to depth.

7.4.4 C/N Ratios

There is a range in C/N ratios from 22:1 to 11:1 throughout the three cores. Core 1, with a mean value of 18:1, has the highest C/N ratio, whereas Core 3, with a mean value of 12:1, has the lowest C/N ratio.

7.4.5 pH Results for all Cores

Table 7.12: pH results from the three cores from Háls.

Sample	pH
CEGC Core 1	5.7
CEGC Core 2	5.8
CEGC Core 3	5.5

The pH results indicate that the soil at Háls is moderately acidic (Brady and Weil 2000) (Table 7.12). These pH results clearly indicate that there are no carbonates present (Dr. J. Robertson, University of Alberta, personal communication 2004).

7.4.6 CEC Results

The CEC results ranged from a minimum of 7.39 me/100g at Core 2 (90-95 cm dbs) to a maximum of 26.07 me/100g at Core 1 (30-35 cm dbs). Core 1, with an average of 19.2 me/100g, has the highest CEC, while Core 2, with an average of 12 me/100g has the lowest CEC.

7.4.7 $\delta^{13}C$ Results

The $\delta^{13}C$ results range from a minimum of -29.3‰ at Core 1 (30-35 cm dbs) to a maximum of -26.4‰ at Core 2 (90-95 cm dbs). All three cores have similar overall $\delta^{13}C$ results. Core 1 becomes slightly depleted with depth, while Core 2 and Core 3 both become more enriched with depth.

7.4.8 $\delta^{15}N$ Results

The $\delta^{15}N$ results range from a minimum of -1.03‰ at Core 2 (35-40 cm dbs) to a maximum of 6.82‰ at Core 3 (15-20 cm dbs). Core 1 and Core 2 have similar average $\delta^{15}N$ content, 1.7‰ and 1.9‰, respectively, but Core 3 is significantly more enriched with an average $\delta^{15}N$ content of 5.8‰.

CHAPTER 8: DISCUSSION

Chemical analysis of soil is a basic approach used to determine the fertility and potential productivity of fields. Chemical analysis has been applied to soils from the Norse farms of GUS and Háls that existed between 1000A.D. and 1350 A.D. (Arneborg 1998; Berglund 1995; Smith 1991a). The soil at each site will be different as a result of the different parent material, climate, and vegetation of each country. However, both sites were occupied by members of the same culture and their land use patterns would therefore have been similar.

GUS provides an opportunity to investigate soil fertility, maintenance, and productivity because the site and its fields were buried and then frozen in permafrost. Therefore, the soil on which the Norse grew their crops is intact and has not been subject to subsequent pedogenic processes. Háls, on the other hand, has been exposed and subject to pedogenic processes since abandonment. The farm and its fields have been incorporated into a nearby farm and Háls continues to be used as pasture for livestock.

8.1 GUS

8.1.1 Unit 2: Pre-Settlement

Geoarchaeological stratigraphic Unit 2 represents the sediment and soil that existed before the Norse arrived in Greenland. This is the soil that sustained the birch woodland that first inspired Eric the Red to settle in the Eastern Settlement.

Unit 2 is present in three of the five sediment cores, STN 5, STN 6, and STN 8. This unit contains approximately 0.08% phosphorus, and without any comparative samples this value is assumed to be a reflection of the natural phosphorus content in a non-anthropogenic Greenlandic soil. Unit 2 contains approximately 2.6% carbon, and approximately 0.2% nitrogen, which are comparable to other non-anthropogenic soils in Greenland (Holowaychuk and Everett 1972; Jakobsen 1986; Tedrow 1970, 1977). The C/N ratios of Unit 2 average 16:1, just outside the usual range for arable soils (8:1 to 15:1). Some Unit 2 C/N values are usual for arable soils, while others are high indicating that the SOM inputs are high in carbon and low in nitrogen and humification has not proceeded to a steady state. (Dr. J. Robertson, University of Alberta, personal communication 2004).

The CEC of Unit 2 ranges from 8.3 to 26.28 me/100g, and shows a general trend of decreasing CEC with depth. As expected the top portion of the unit, the A-horizon of a palaeosol, has a higher CEC. The CEC of Unit 2 is similar to the CEC of natural soils from other areas of Greenland (Holowaychuk and Everett 1972; Jakobsen 1986; Tedrow 1970, 1973, 1977). As expected, present day soils developing on Greenland's landscape have very much the same chemical properties as the soil that developed before the Norse arrived.

The $\delta^{13}C$ average value for Unit 2 is -26.3‰ with a standard deviation of 0.3‰. This is typical of soil supporting C_3 plants that average -27‰, but this can range anywhere between -35‰ and -21‰ (Kelly 2000) (Table 4.1).

The $\delta^{15}N$ results for Unit 2 average 8.8‰ (StDev=5.0‰), and range between 5.8‰ and 16.5‰. As variable as Unit 2 $\delta^{15}N$ results are, they are typical of soils, which can range from 2 to 12‰ (Kelly 2000) (Table 4.1).

8.1.2 Unit 2/3 Boundary

The Unit 2/3 boundary marks the beginning of Norse occupation. At the Unit 2/3 boundary the concentration of phosphorus, carbon, nitrogen and CEC increases significantly. Anthropogenic soils usually have twice the amount of phosphorus of naturally occurring soil (Entwistle et al. 2000; Provan 1973), and this appears to be the case in three of the five cores in which, the phosphorus levels double, from Unit 2, the naturally occurring soil, to Unit 3, the anthropogenic soil of Norse occupation. The phosphorus content of the cores thus reflects the boundary between Pre-Settlement and Norse Occupation.

The carbon and nitrogen concentration increases significantly from Pre-Settlement to Norse Occupation. Pre-settlement soil contains about 3% carbon, but this increases to about 13% following Norse occupation. Nitrogen content increases from 0.2% in the Pre-Settlement soil to 1.1% in the Norse Occupation soil. The six-fold increase in nitrogen was probably not the result of fixation of atmospheric nitrogen by legumes or lichens. The pollen diagram for GUS (Figure 1.5) unfortunately records few leguminous plants present. However, being insect pollinated, legumes rarely enter the pollen record. Even though legumes and lichens are present in the area and capable of fixing atmospheric nitrogen, an increase of this magnitude occurring with Norse occupation is no doubt a result of human intervention. The nitrogen was concentrated by importing vegetation and manure into the infield.

The increase in both carbon and nitrogen is an indicator of the addition of organic matter through intentional fertilization. Fertilizers can be composed of manure, seaweed, or household wastes, which mineralize much more rapidly than nitrogen from much of the soil organic matter, substantially increasing the amount of nitrogen available in the soil (Brady and Weil 2000).

The C/N ratio decreases from 16:1 in Unit 2 to 12:1 in Unit 3 with occupation. The C/N ratio of arable soils ranges from 8:1 to 15:1, the median being near 12:1, which is optimal (Gregorich et al. 1994). The amount of nitrogen to carbon is very important to the survival of soil microbes. If the carbon to nitrogen ratio of organic matter is high, soil microbes will use mineral nitrogen from the soil; they will be in competition for mineral nitrogen with plants (Brady and Weil 2000). The change in the C/N ratios observed at the Unit 2/3 boundary suggests that the Norse improved the soil upon their arrival to include more nitrogen from manure and household wastes thereby making it suitable for agriculture.

The CEC of the soil increases significantly at the Unit 2/3 boundary. At the time of Norse arrival the CEC was at an average of 16.6 me/100g but increased to an average of 47 me/100g. A change in pH could account for the increase in CEC, but Units 2 and 3 are both acidic. Unit 2 is known to be slightly acidic because of published pH results of Greenlandic soil. Therefore, the increase in CEC is a result of fertilizer application. The increase in organic matter through fertilization would have added humus to the soil thereby increasing the CEC of the soil.

Norse settlement led to the two-fold increase in phosphorus content; and increases in carbon, nitrogen, and CEC. These results demonstrate that the Norse actively changed the soil through the use of manure to create a soil that was improved for their agricultural needs.

8.1.3 Unit 3: Norse Occupation

As noted above, the phosphorus, carbon, nitrogen concentrations and CEC increase significantly from Unit 2 to Unit 3, but Unit 3 also exhibits some variation. Except for STN 5, the carbon, nitrogen and CEC are generally at a maximum near the top of Unit 3 and at a minimum at the base of Unit 3. This is likely a result of decomposition processes that occurred during Norse occupation rather than a reflection of intensification in fertilizer application.

The organic carbon content of Greenland soils can be as low as 1.2 %, to 0.1% (Holowaychuk and Everett 1972; Jakobsen 1986; Tedrow 1970; Tedrow 1977). The carbon content of soil from other Greenland Norse sites is higher than natural soil and comparable to the 14% carbon result from GUS (Rutherford 1995).

The C/N ratios throughout Unit 3 remain fairly constant at 12:1 indicating that the Norse activity maintained a carbon to nitrogen ratio suitable for agriculture throughout the entire period of occupation.

The pH of Unit 3, the anthropogenic soil, averages 6, which is moderately acidic (Brady and Weil 2000). This is within the pH values for natural podzols in Southern Greenland (Jakobsen 1992), but slightly more basic than for other anthropogenic soils there (Rutherford 1995), and probably due to the fact that Unit 3 was buried and then frozen. At pH 6 the soil is not strongly leached. Any soil with a pH between 5.5 and 7.0 has practically 100% base saturation (Magdoff and Bartlett 1985). Plant nutrients are more readily available in soils whose pH range is between 5.5 and 7.0 (Brady and Weil 2000).

The exchangeable cations for Unit 3 are higher than for natural soils in Greenland (Jakobsen 1986, Tedrow 1970, 1977), and for other archaeological soils in Greenland. It is lower in sodium than reported by Rutherford (1995) who attributes to the proximity of his sample locations to the seawater in the fjords. The CEC of Unit 3 from GUS is higher than other archaeological infields in Greenland because the GUS infield soil was buried beneath alluvium and locked in permafrost. The GUS infield soil has not been susceptible to erosion or pedogenic processes, which can alter the CEC.

The chemical components of all the sediment cores increase in Unit 3; however, the amount by which the components increase is not consistent for all the cores. Unit 3 is thinnest furthest from the buildings at STN 8 (10 cm), and has the lowest levels of carbon, nitrogen, and exchangeable cations. Unit 3 is thickest closest to the site at STN 2 (at least 29 cm), STN 5 (57 cm), and STN 6 (21 cm) and contains the maximum values for those chemical components analyzed (Figure 8.1). This indicates that organic inputs were not evenly distributed throughout the tun. Two different agricultural strategies could be responsible for these results.

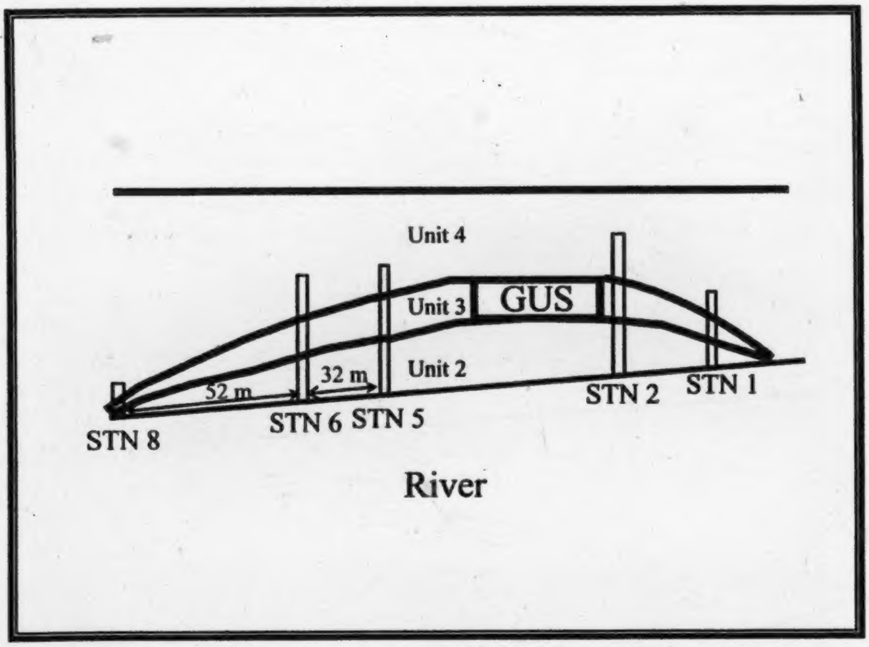

Figure 8.1: Profile view of the GUS area showing relative thickness of Unit 3 declining away from GUS.

The first possibility is that during the period of Norse occupation at GUS the infield was enlarged because the cooling climate would have resulted in lower tun yields. Increasing the size of the tun will increase the total yield. Areas that were previously left fallow would be fertilized and kept away from grazing animals. This would result in less development of anthropogenic soil and therefore lower concentrations of carbon, nitrogen, and exchangeable cations. However, there are no remnants of a previous tun wall that would suggest the field had been enlarged.

The second and more probable explanation for the spatial difference of Unit 3 is that systematic fertilization of the entire infield was not practiced by the Norse at GUS. This could be because there was a lack of labour to distribute the manure, or perhaps the Norse did not view the distribution of the manure as important. The soil chemistry results are similar to those of Simpson (1994, 1997) who showed that the key chemical concentrations and soil thickness decreased away from the center of Norse farms in Orkney.

The $\delta^{13}C$ values of Unit 3 (mean = -26.9‰) do not differ significantly to those of Unit 2 (mean = -26.2‰). This indicates that the Norse added only terrestrial C_3 derived inputs to the soil. Therefore, unlike other Norse settlements in Orkney, Shetland, Scotland, and Iceland (Ambers 1994, Fenton 1978, 1985; Hallsson 1964), there is no evidence of marine plants used as a fertilizer, as marine plants have significantly higher $\delta^{13}C$ values (Table 4.1).

There is no significant difference between the $\delta^{13}C$ values of the samples of ancient dung and modern vegetation collected from GUS, and from Unit 3 soil (Table 7.2 and 7.3). The $\delta^{13}C$ values of the dung and soil are similar indicating that the fertilizer was composed primarily of the dung from the farm animals. The $\delta^{13}C$ values of the dung are also similar to those of the vegetation, indicating that the diet of the animals was made up of the C_3 plants as very little fractionation of ^{13}C takes place when consumed by animals (DeNiro 1987; DeNiro and Epstein 1978; Kelly 2000; Peterson and Fry 1987). The similarity of the $\delta^{13}C$ values of the dung, vegetation, and the soil, indicates that the local vegetation was used to feed the animals, and their dung was subsequently used to fertilize the land, which supported the vegetation that made up much of their diet.

Interestingly, $\delta^{13}C$ values of bone collagen obtained from GUS are enriched by about 6‰ compared to vegetation (Table 7.3), (Arneborg 2001, 2003). Enrichment in $\delta^{13}C$ values of the consumer compared to the diet is less than 2‰ (DeNiro 1987; DeNiro and Epstein 1976, 1978; Kelly 2000; Peterson and Fry 1987; Sillen et al. 1989; Tauber 1981; van der Merwe 1982; van der Merwe and Vogel 1978). However, the $\delta^{13}C$ values of the bone collagen from herbivores can be enriched by 4-6‰. This accounts for the 6‰ difference observed between the vegetation and diet for GUS as seen in Table 7.7 and 7.8. However Kelly (2000) cautiously points out that in these studies where a 6‰ difference was observed the actual composition of the diets were unknown. The $\delta^{13}C$ values from bone of white-tailed deer (-19.6‰), reindeer (-19.6), and bison (-20.6‰) are similar to the results obtained by Arneborg (2001, 2003)(Bocheron et al. 1994; Chisholm et al. 1986; Kelly 2000).

The $\delta^{15}N$ values of Unit 3 from all stations (mean= 8.4‰) do not vary significantly from those of Unit 2 (average 6.8‰) and are close to the average soil $\delta^{15}N$. Overall, the $\delta^{15}N$ values increase with depth in Unit 3, as is expected in naturally occurring soil (Peterson and Fry 1987). The $\delta^{15}N$ values of dung vary from 2.3‰ to 3.2‰. The soil will be slightly higher than the dung because plants will preferentially take in the lighter isotope leaving the heavier isotope behind in the soil. The nitrogen results indicate that legumes were not grown on the infield soil. The $\delta^{15}N$ result of the marine plant collected along the Nuuk coast during this study is around 5‰. The values obtained from the seaweed sample are similar to expected soil values and are therefore not useful in determining whether seaweed was used as a fertilizer (Table 4.1).

8.1.4 Unit 3/4 Boundary

The change in phosphorus, carbon, nitrogen, and CEC values between Unit 3 and Unit 4 is even more distinct than the change between Unit 2 and Unit 3. From Unit 3 to Unit 4 the phosphorus, carbon, nitrogen, and CEC concentrations fall off markedly. This boundary records the end of Norse occupation at GUS. Only at STN 2 do the δ^{13}C and δ^{15}Nvalues correlate with the stratigraphic units, with the highest values in Unit 4. None of the other cores show any correlation with the stratigraphic units.

8.1.5 Unit 4: Post Abandonment

Unit 4 represents the Post Abandonment period. Concentrations of soil elements are very low, typical of alluvial sediment deposited over the entire site. The phosphorous, carbon, and nitrogen levels in Unit 4 drop below Pre-Settlement levels and are unsuitable for agriculture. Sodium differs from the other cations as the highest levels of sodium occur at the top of the profile in Unit 4. The sodium levels increase throughout the entire profile from Pre-Settlement to Norse Occupation to Post-Abandonment. The higher levels of sodium are similar to results obtained by Rutherford (1995), although Rutherford obtained much higher concentrations of exchangeable sodium. Rutherford (1995) attributes the high sodium levels to sea spray because of the proximity of seawater in the fjords. Unlike Rutherford's sites, Hvalsey, Gardar, Brattahlid, and Godthåb areas, which are located on fjords, GUS is located on a river derived from the glacier, Kangerlusarssungusp Taserssua. GUS is located approximately 13 km from the nearest fjord, Ameralla fjord, and therefore, there would be only a small amount, if any, of sea spray that makes it as far as GUS.

8.2 ICELAND

8.2.1 CEGC Core-1: The Outfield

This control core represents the natural soil chemistry in the Háls area. The phosphorus levels remain constant, around 0.15%, throughout the profile and are about double those for Greenland (0.08%). In general, Icelandic soils have naturally higher phosphorus values than those from Greenland, because volcanic soils contain large amounts of allophone, which have high phosphate fixing abilities (Brouwere et al 2003, Bjarni Helgason, Agriculture Research Institute, Iceland, personal communication 2000).

The carbon levels show very little variation, averaging 27%, which is indicative of a poorly drained soil in Iceland (Helgason 1968). Because the core was collected from a wet decomposed peat, these results are very high compared to other Icelandic soils (Strachan et al. 1998). The carbon content is constant throughout the profile and therefore indicates that the carbon input has been constant over time, and there has been little decomposition of the moss that formed the peat (Dr. J. Robertson, University of Alberta, personal communication 2004).

The nitrogen results show a general trend of increasing nitrogen content with depth. Dr. J Robertson (University of Alberta, personal communication 2002) suggests that this result may occur because the organic matter at the surface is less decomposed. Nitrogen levels may be lower at the surface because nitrogen has been lost through volatilization, or the nitrogen has leached into the bottom portion of the profile as some forms of nitrogen are loosely held in the soil and easily leached. Nitrogen values average 1.6 % and are in the range of Icelandic poorly drained soils (Helgason 1968).

The C/N ratio of the control core is high, 18:1, above the optimum ratio for agricultural soils. The ratio is greatest near the surface and declines with depth. This is because decomposition increases with depth and some carbon is lost at CO_2, therefore the C/N ratio becomes narrower. The C/N ratios within CEGC Core-1 are similar to those of O-horizons of some other soils within the Thingvallavatn area of Iceland (SW Iceland) (Thorsteinsson and Arnalds 1992).

The total CEC ranges from 15.76 to 26.07 me/100g. These levels are not as high as other poorly drained organic soils in Iceland (Helgason 1968), but they are higher than results obtained by Thorsteinsson and Arnalds (1992). The total CEC of the outfield core tends to increase with depth. The increase in CEC with depth is a reflection of an increase in humus, an organic colloid. Humus is produced from the decomposition of fresh organic matter, and organic matter lower in the profile has undergone more decomposition than organic matter higher in the profile (Dr J. Robertson, University of Alberta, personal communication 2002).

The $\delta^{13}C$ stable isotopes of the control core average –28.9‰ with little variation. This is an expected $\delta^{13}C$ value for soil supporting terrestrial C_3 plants. The $\delta^{15}N$ values of the outfield core are fairly constant around 1.65‰. This value is very depleted compared to the average $\delta^{15}N$ value of soil (9‰) (Table 4.1). The $\delta^{15}N$ value is closer to that of legumes (1‰) and C3 plants (3‰).

8.2.2 CEGC-Core-2: The Infield

The phosphorus levels in CEGC Core-2 are somewhat more variable compared to the outfield core. Because of the immobility of phosphorus the interval between 5 to 85 cm dbs, which shows an increase in phosphorus compared to CEGC Core-1, may be attributed to human presence at the site. Although, there is an increase in phosphorus between outfield and infield cores, the difference is relatively small at 0.03%. This would indicate that this area received little or no additional phosphorus rich material of anthropogenic origin. As shown at GUS, and in Orkney (Simpson et al. 1999) fertilizer was not evenly distributed throughout the infield, and this section of the infield located near the tun wall may not have received frequent applications of manure.

The carbon and nitrogen levels of the infield core are significantly lower and are more variable when compared to the outfield core. The carbon concentrations within this soil core are on the high end of typical Icelandic soils. The carbon and nitrogen levels are indicative of a more freely drained soil, (Helgason 1968) which contains more mineral material than CEGC-1. Generally, there is an overall trend of decreasing carbon and nitrogen content with depth, and the organic matter is more decomposed within this core. There may be overall less carbon and nitrogen in the infield when compared with the outfield, but the C/N ratios of the infield soil are more usual to arable fields. The overall C/N ratio of Unit 2 within this core is 15:1, which falls just within the expected value for arable soil. This ratio is similar to other C/N ratios of soils within Iceland (Helgason 1968; Thorsteinsson and Arnalds 1992).

The total CEC of the infield core is less than that of the outfield core. On the whole the total CEC of CEGC Core-2 is relatively constant throughout the profile at 12 me/100g. The exception to this occurs at 45-50 cm dbs. There are no discernable lithological changes within the profile at 45-50 cm dbs that may account for a decrease in CEC at that level.

The $\delta^{13}C$ results and $\delta^{15}N$ results of the infield core are very slightly enriched (1‰) compared to the outfield core. Overall, the stable isotopes become more enriched with depth, which is what is expected in soil (Peterson and Fry 1987).

8.2.3 CEGC Core-3: The Farm Buildings

Core 3 was taken next to the farm buildings and the phosphorus levels from this location are approximately double those of the outfield and infield cores. Phosphorus levels are highest between 15-30 cm dbs and 40-50 cm dbs suggesting two periods of occupation instead of one continuous occupation of the area. These two periods would reflect the times when the site was first occupied as a smithy and then again as a farm. However, analysis of organic phosphate should be completed to determine whether this is just a translocation of inorganic phosphate or two distinct periods of occupation.

The carbon and nitrogen levels decrease slightly with depth, however they are much more constant than the carbon and nitrogen levels of the infield core. The carbon and nitrogen concentrations are indicative of a freely drained soil (Helgason 1968). The only increase in carbon content occurs in the top 20 cm and this is a reflection of the organic material that has yet to decompose. The stability of the carbon levels indicates that the amount of organic matter input versus mineral matter input has remained constant over time. Although the carbon and nitrogen concentrations are lower than those for the other cores the C: N ratio is 12:1, which is optimal for an arable field.

Total exchangeable bases in CEGC Core-3 range from 7.65 to 19.75 me/100g. There is a general increase in the CEC at 40cm dbs. The CEC is higher in CEGC Core 3 than for CEGC Core-2, indicating the increase capability of the soil to retain soil nutrients.

The $\delta^{13}C$ results for CEGC Core-3 are only slightly more enriched, ~1‰, than in the CEGC Core-2. The soil becomes enriched with depth, as expected, and it is not as variable as the other two cores. The $\delta^{15}N$ results for CEGC Core 3 are enriched by about 4‰ compared to CEGC Core-2, although Core 2 has a lot of variability. The $\delta^{14}N$ results for CEGC Core-3 are more indicative of terrestrial non-legume plants, while the $\delta^{15}N$ results of CEGC Core-1 and 2 are more indicative of terrestrial legumes, which use atmospheric derived nitrogen.

The soil chemistry results from Háls, Iceland, exhibit some of the same spatial trends one finds at GUS. The core nearest the tun wall shows chemical results very similar to those of the core taken outside of the infield, while the chemical results of the core taken closest to the farm buildings shows increased concentrations of nutrients.

The organic matter of the soil from Iceland is more decomposed than the soil from Greenland. This is because the soil from Greenland has been in a period of stasis since it was covered by alluvium and enveloped within the permafrost and has had no opportunity to continue to decompose.

Comparing the carbon and nitrogen results from both sites, GUS and Hals, shows that despite the different trends observed, the actual concentration of carbon and nitrogen in the anthropogenic soils are very similar. The carbon levels in GUS increased to 10%, whereas the carbon levels at Hals, in CEGC Core-3, decreased to 9%. The nitrogen levels of Unit 3 of GUS increased to 1.2%, while in CEGC Core-3 the nitrogen levels decreased to 0.8%.

9.0 CONCLUSION

Chemical analysis was carried out on two Norse farms from Greenland and Iceland that were occupied during the European Medieval Period. The ability to maintain the productivity of the infields was paramount to the survival of the agricultural portion of their pastoral/hunting mixed economy. During the period of Norse occupation the inhabitants of the farms relied heavily on the harvest from the tun to provide enough food to see the animals through the long winter. Heavy reliance on a field can lead to soil exhaustion. It was therefore crucial, that the tun remained productive.

In this thesis four research questions were asked to determine whether the Norse agricultural strategy of the infield was sufficient for maintaining soil fertility, or if with time the soil became depleted of nutrients at GUS.

1. Did the Norse, upon their arrival, affect the concentration of key chemical constituents of the infield soil?

Comparison of the chemical properties of Units 2, 3 and 4 determined the degree of impact the Norse had on the soil at GUS. Increases in key chemical constituents (phosphorus, nitrogen, and exchangeable cations) indicate that the Norse positively impacted the infield soil upon their arrival. The Norse applied manure to the infield thereby raising the carbon, nitrogen and CEC of the soil, and making it adequate for agriculture.

2. And if so, how did the infield soil change during the time that the Norse occupied the farms at GUS and Háls?

At GUS, the carbon, nitrogen, and CEC levels are generally at a maximum near the top of Unit 3 and at a minimum at the base of Unit 3. This is likely a result of decomposition processes that occurred during Norse Occupation rather than a reflection of intensification in fertilizer application, as soils naturally have higher concentrations of nutrients near the surface. This shows that over time the soil does not become depleted in key nutrients but is maintained. The ability of the Norse to maintain high levels of nutrients indicates that they possessed sufficient knowledge about the soil system to actively manipulate their ecosystem for beneficial results.

At Háls initial phosphorus analysis of the cores was able to detect two depths with increased phosphate, which perhaps reflects the two periods of occupation when the site was used first as a smithy and then as a farm. The chemical analysis of the two cores that occur within the infield, show a general trend of decreasing carbon and nitrogen with depth, and the exchangeable cations are generally constant throughout the core. As with GUS, an increase in carbon and nitrogen towards the surface is probably a result of the decomposition process, and not an indication of farming practices. Overall, there is no significant change that occurs within the cores that corresponds with the arrival of the Norse. Any changes that may have occurred may have been obliterated by the years of exposure to the elements

3. Was fertilizer distributed across the entire infield at GUS and Háls?

At both GUS and Háls there are marked spatial distinctions in the total phosphate, carbon, nitrogen and exchangeable cation concentrations within the anthropogenic soil and these can be interpreted as reflecting differences in the depositional pattern of organic material. There is a general trend of declining total phosphate values with distance from the farmstead, suggesting that the intensity of fertilizer application has been consistently greater closer to the farmstead. The anthropogenic soil from GUS and Háls has more nutrients and becomes thicker closer to the farm buildings.

This is similar to other Norse farm sites of the same period in Orkney, where manure appears to have been removed from the barns, and dumped on the field with little consideration to systematic fertilizing of the entire infield (Simpson 1994, 1997; Simpson et al. 1999). Concentration of the fertilizer closest the building from which it was removed appears to be part of the agricultural practice of the Norse.

4. What was the origin of the fertilizer? Did the Norse at GUS and Háls strictly use animal manure, or did they also use seaweed as a fertilizer?

The Norse were able to maintain the nutrient levels of the soil by applying fertilizers to the infield. Stable isotope analysis was employed to determine the origin of fertilizer sources. The results of δ^{13}C and δ^{15}N tests indicate that fertilizer was composed primarily of terrestrial sources. There is no evidence that legumes or marine sources of fertilizer were used.

The results from Háls differ from those of GUS in that the infield at Háls has lower concentrations of nutrients than the control soil. However, comparison of the actual values obtained from carbon and nitrogen from the infield of the two sites were similar, and the C/N ratios of both infields were optimal for agriculture.

The data obtained within this thesis suggests that soil nutrient depletion is not an explanation for the abandonment of GUS in Greenland. The data supports preliminary observations made by McGovern et al. (1988) that "... it seems clear that the Norse very purposefully attempted to improve the productivity of pastures in the homefields near the farms." Work completed at GUS by the Greenlandic/Danish research team suggests that GUS was abandoned because of the hydrological changes of the area as a consequence of climate change deposited large amounts of sediment over the farm (Arneborg and Gulløv 1998, Schweger 1998). Perhaps other farms in the region may have been abandoned for the same reasons and not from unsustainable soil use. If this is the case, then the theory that the Norse were responsible for their own disappearance through non-sustainable land use practices is not valid within this region of Greenland.

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APPENDICES

APPENDIX I: FAUNAL REMAINS FOUND ON NORSE FARM SITES

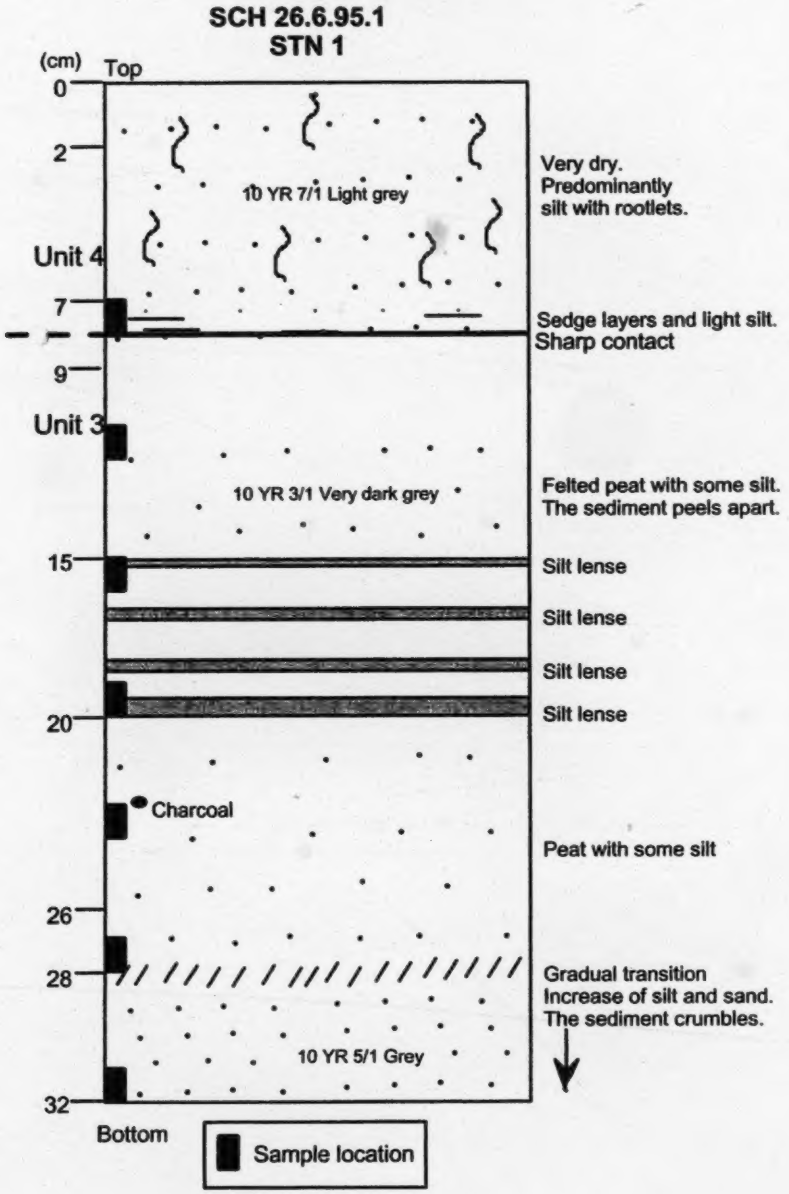
Land Mammals	
Domestic Animals	
Common Name	**Latin Name**
Cow	*Bos taurus*
Sheep	*Ovis aries*
Goat	*Capra hircus*
Pig	*Sus scrofa*
Horse	*Equus caballus*
Dog	*Canis familiarus*
Wild Animals	
Caribou	*Raniger tarandus*
Arctic hare	*Lepus arcticus*
Arctic fox	*Alopex lagopus*
Polar bear	*Ursus martimus*
House mouse	*Mus musculus*
Water Mammals	
Walrus	*Odobenus rosmanus*
Beluga Whale	*Delphinaptera leucas*
Pilot whale	*Globicephalus melas*
Southern right whale	*Balena australis*
Humpback whale	*Megaptera novaeangliae*
Narwhale	*Monodon monoceros*
Great and small whales	*Cetacea sp.*
Whiteback dolphin	*Legenorynchus albirostris*
Harp seal	*Pagophilus groenlandicus/ Phoca groenlandica*
Hooded seal	*Crystophora cristata*
Ringed seal	*Phoca hispida*
Harbour/Common seal	*Erignatus barbatus/ Phoca vitulina*
White fronted porpoise	*Lagenorychus albirostris*
Harbour/Common porpoise	*Phocoena phocoena*
Birds	
Erne/White-tailed eagle	*Haliaetus albiculla*
Little Auk/Dovekie	*Alle alle*
Common eider	*Somateria mollissima*
King eider	*Somateria spectablilis*
Gyr falcon	*Falco rusticolus*
Common Guillemot/Murre	*Uria aalge*
Thick billed Murre	*Uria lomvia*

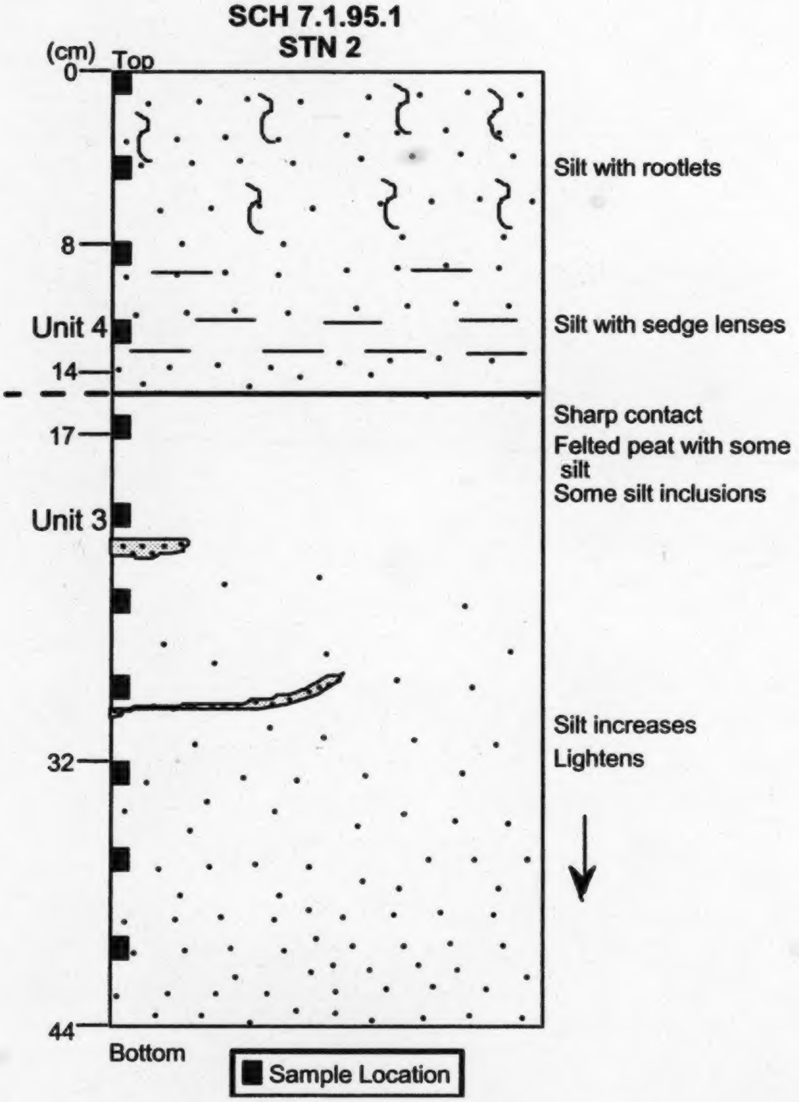
Black Guillemot	*Cepphus grylle*
Mallard	*Añas playrynchus*
Rock Ptarmigan	*Lagopus mutus*
Razorbill	*Alca torad*
Iceland gull	*Larus glaucoides*
Great northern Loon	*Gavia immer*
Red-throated Loon	*Gavia stellata*
Kittiwake	*Rissa trydactyla*
Common Raven	*Corvus corax*
Northern pintail	*Anas acutas*
Whooper swan	*Cygnus cygnus*
Tundra/Whistler swan	*Cygnus musicus*
Common redpoll	*Carduelis flammea*
Common puffin	*Fratercula arctica*
Fish	
Capelin	*Mallotus villosus/ medina sp.*
Atlantic cod	*Gadus morhua*
Arctic char	*Salvelinus alpinus*
Shorthorn sculpin	*Myoxocephalus scropius*
Atlantic halibut	*Hippoglossus hippoglossus*
Salmon	*Salmo sp.*
Invertebrates	
Blue mussel	*Mytilus edulis*
Whale barnacle	*Coronula diadema*
Clams	*Mya sp.*
Shellfish	*Mollusca sp.*

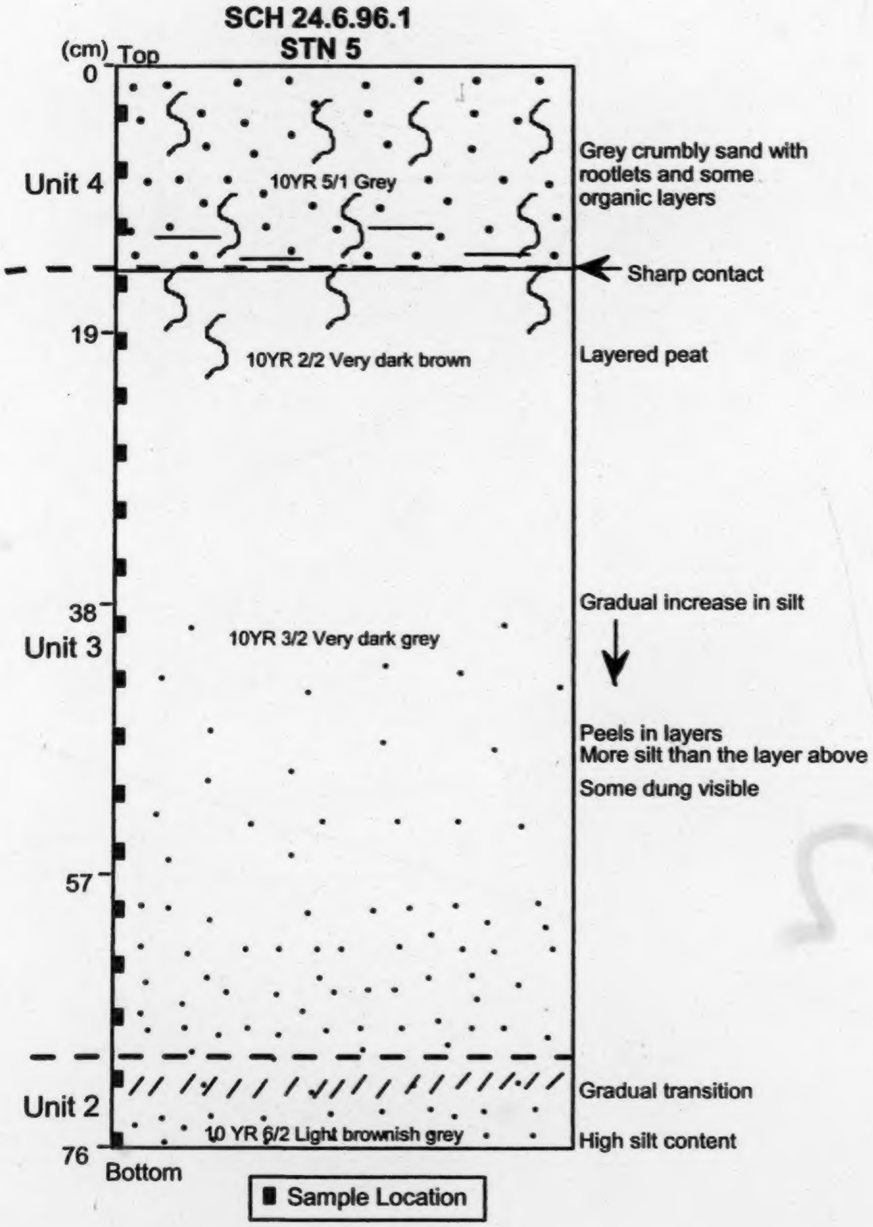
Compiled from Enghoff 2003 McGovern 1985, McGovern et al 1996, McGovern et al 1983, and Vebæk 1991.

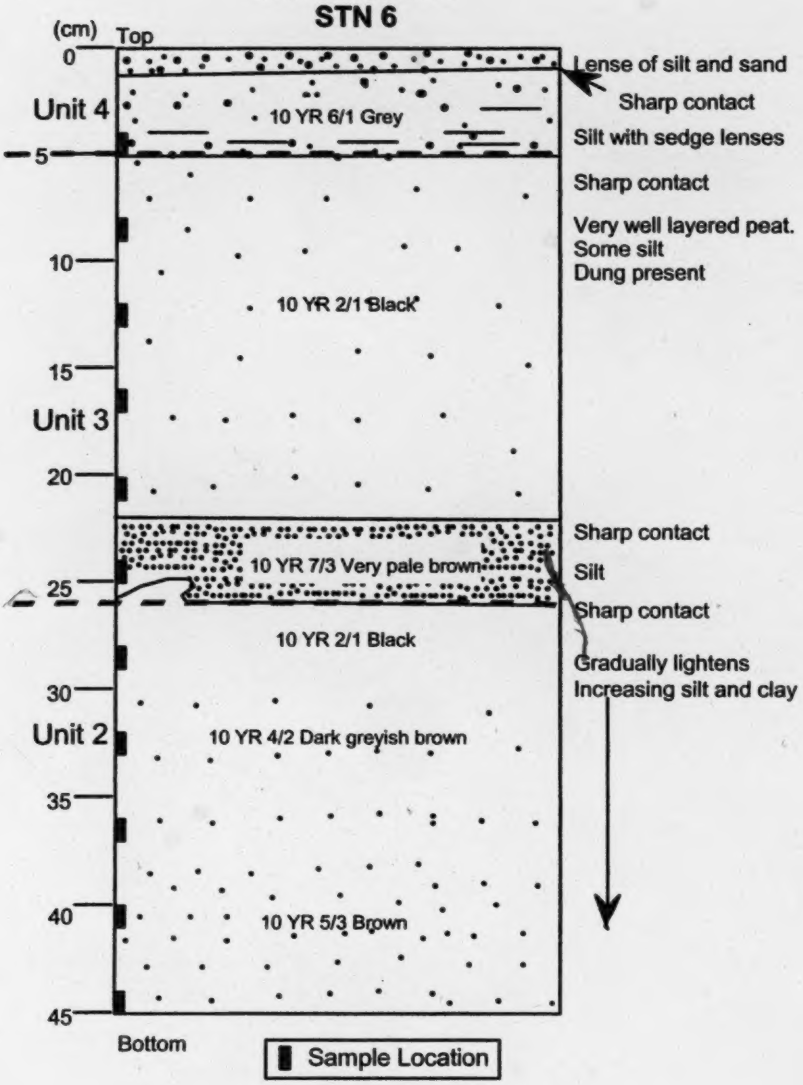
APPENDIX II: SOIL PROFILES

Greenland Soil Cores


SCH 26.6.95.1
STN 1
(cm)
Top
0
2
Unit 4
7
9
Unit 3
15
20
26
28
32
Bottom
10 YR 7/1 Light grey
Very dry. Predominantly silt with rootlets.
Sedge layers and light silt.
Sharp contact
10 YR 3/1 Very dark grey
Felted peat with some silt. The sediment peels apart.
Silt lense
Silt lense
Silt lense
Silt lense
Charcoal
Peat with some silt
Gradual transition Increase of silt and sand. The sediment crumbles.
10 YR 5/1 Grey
Sample location

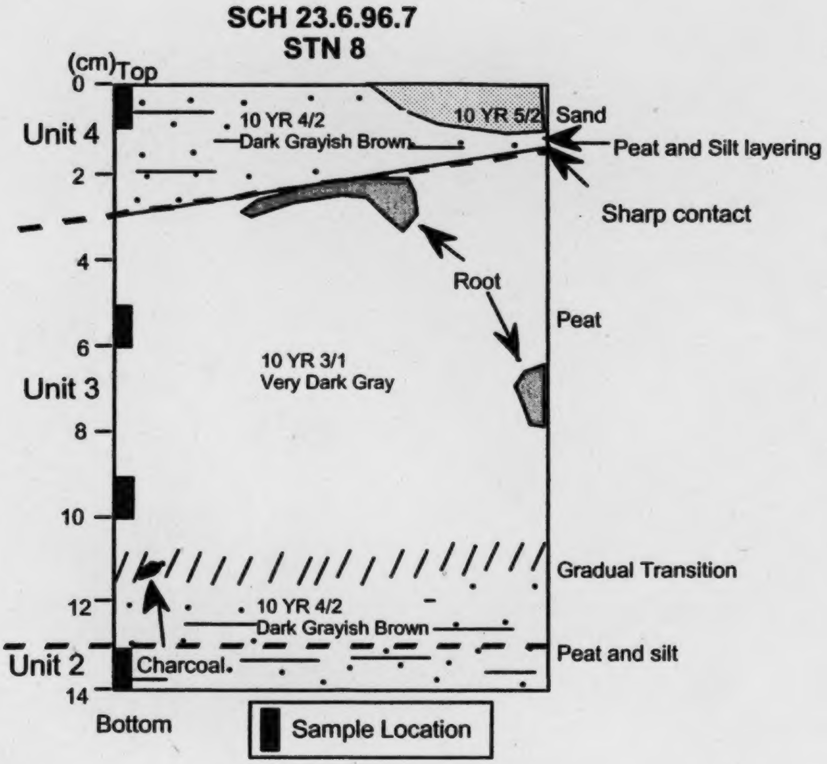

SCH 7.1.95.1
STN 2
(cm)
Top
0
8
Unit 4
14
17
Unit 3
32
44
Bottom
Silt with rootlets
Silt with sedge lenses
Sharp contact
Felted peat with some silt
Some silt inclusions
Silt increases
Lightens
■ Sample Location


SCH 24.6.96.1
STN 5
(cm)
Top
0
19
38
57
76
Bottom
Unit 4
Unit 3
Unit 2
10YR 5/1 Grey
10YR 2/2 Very dark brown
10YR 3/2 Very dark grey
10 YR 6/2 Light brownish grey
Grey crumbly sand with rootlets and some organic layers
Sharp contact
Layered peat
Gradual increase in silt
Peels in layers
More silt than the layer above
Some dung visible
Gradual transition
High silt content
▮ Sample Location



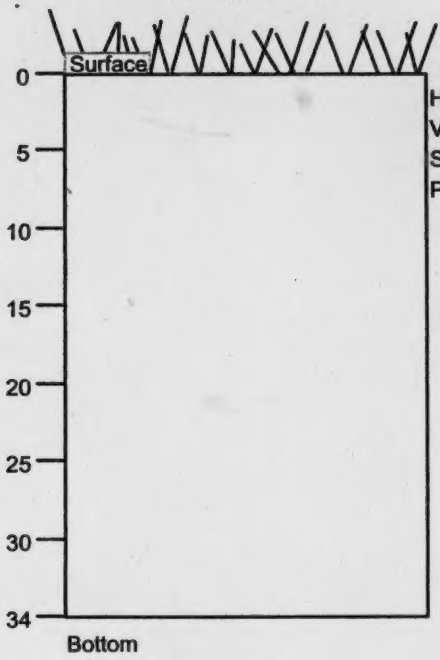
SCH 23.6.96.7b
STN 6

(cm)
Top
0
5
10
15
20
25
30
35
40
45
Bottom
Unit 4
Unit 3
Unit 2
10 YR 6/1 Grey
10 YR 2/1 Black
10 YR 7/3 Very pale brown
10 YR 2/1 Black
10 YR 4/2 Dark greyish brown
10 YR 5/3 Brown
Lense of silt and sand
Sharp contact
Silt with sedge lenses
Sharp contact
Very well layered peat.
Some silt
Dung present
Sharp contact
Silt
Sharp contact
Gradually lightens
Increasing silt and clay
Sample Location


SCH 23.6.96.7
STN 8
(cm)
Top
0
2
4
6
8
10
12
14
Bottom
Unit 4
Unit 3
Unit 2
10 YR 4/2
Dark Grayish Brown
10 YR 5/2
Sand
Peat and Silt layering
Sharp contact
Root
Peat
10 YR 3/1
Very Dark Gray
Gradual Transition
10 YR 4/2
Dark Grayish Brown
Peat and silt
Charcoal
Sample Location

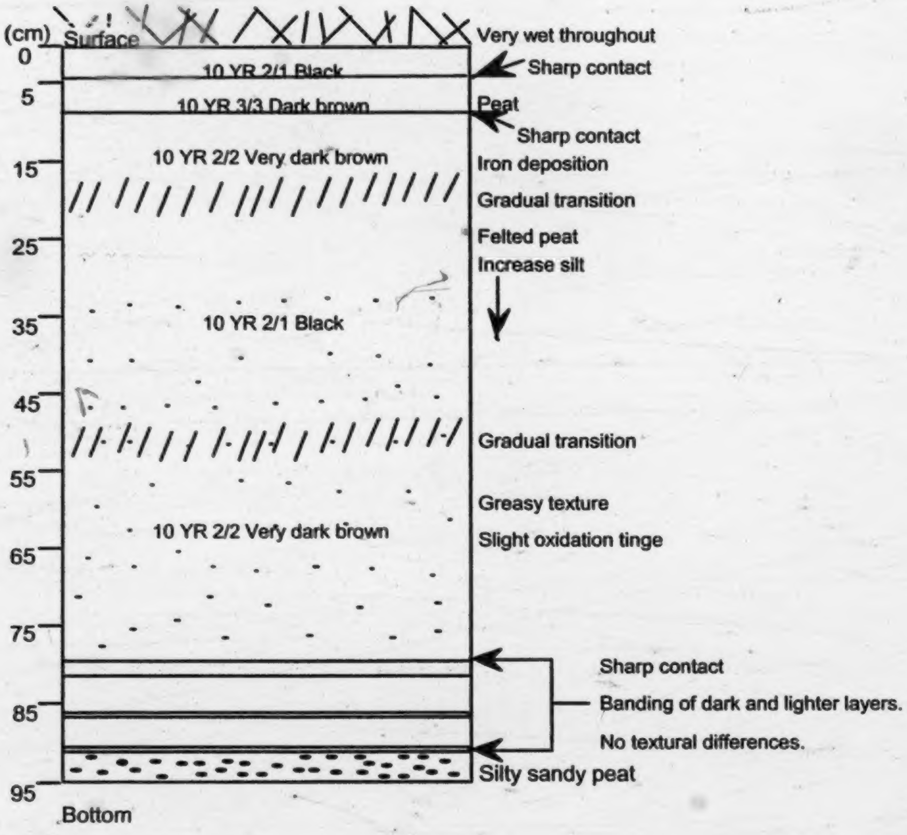
ICELAND SOIL CORES

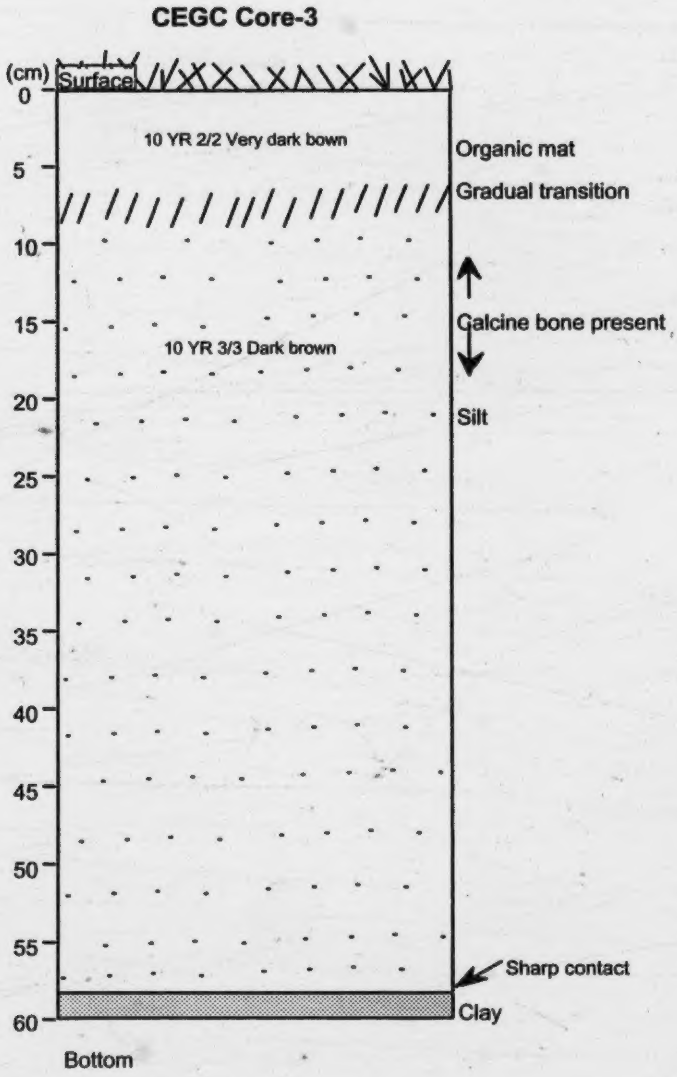
CEGC Core-1


Surface
0
5
10
15
20
25
30
34
Bottom

Homogenous throughout
Very wet
Small pieces of organic matter
Peat

CEGC Core 2


(cm)
Surface
0
5
15
25
35
45
55
65
75
85
95
Bottom
10 YR 2/1 Black
10 YR 3/3 Dark brown
10 YR 2/2 Very dark brown
10 YR 2/1 Black
10 YR 2/2 Very dark brown
Very wet throughout
Sharp contact
Peat
Sharp contact
Iron deposition
Gradual transition
Felted peat
Increase silt
Gradual transition
Greasy texture
Slight oxidation tinge
Sharp contact
Banding of dark and lighter layers.
No textural differences.
Silty sandy peat


CEGC Core-3
(cm)
Surface
0
5
10
15
20
25
30
35
40
45
50
55
60
10 YR 2/2 Very dark bown
Organic mat
Gradual transition
Calcine bone present
10 YR 3/3 Dark brown
Silt
Sharp contact
Clay
Bottom

APPENDIX III: DATA FOR SOIL CORES

Greenland

Results for STN 1

Depth (cm)	Unit	P (%)	C (%)	N (%)	CEC (me/100g)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
7-8	4	0.087	12.9	0.908	30.45	25.97	3.95	0.23	0.3	-26.58	5.17	14:1
11-12	3	0.112	22.4	1.672	69.85	61.97	7.38	0.23	0.26	-27.69	7.91	13:1
15-16	3	0.131	12.8	0.8	39.43	34.47	4.45	0.25	0.27	-27.49	8.05	12:1
19-20	3	0.261	15.3	1.339	48.57	43.97	3.95	0.23	0.43	-27.27	7.84	12:1
23-24	3	0.156	13.6	1.105	46.59	42.47	3.65	0.22	0.25	-27.07	7.38	12:1
27-28	3	0.109	12.2	0.974	36.95	33.47	3.07	0.18	0.22	-27.05	6.02	12:1
31-32	3	0.105	6.93	0.509	29.55	26.47	2.78	0.14	0.16	-26.6	4.46	15:1

Reults for STN 2

Depth (cm)	Unit	P (%)	C (%)	N (%)	CEC (me/100g)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
0-1	4	0.047	1.55	0.064	7.13	5.66	0.77	0.19	0.51	-27.63	4.86	30:1
4-5	4	0.037	1.75	0.084	7.56	6.1	1.08	0.16	0.23	-26.38	4.66	30:1
8-9	4	0.042	2.58	0.097	11.04	9.41	1.3	0.15	0.18	-26.38	5.58	31:1
12-13	4	0.035	3.23	0.153	10.46	9.04	1.3	0.09	0.04	-26.25	5.27	12:1
16-17	3	0.068	10.88	0.929	43.16	37.1	5.3	0.18	0.58	-26.98	10.03	12:1
20-21	3	0.21	22.32	1.891	63.34	55.85	6.74	0.32	0.43	-27.48	9.7	13:1
24-25	3	0.257	20.31	1.708	64.45	56.22	7.3	0.42	0.51	-27.25	9.2	13:1
28-29	3	0.199	20.7	1.789	66.52	60.35	5.55	0.34	0.28	-27.12	8.78	13:1
32-33	3	0.15	16.33	1.377	68.48	62.6	5.3	0.34	0.24	-27.23	6.9	12:1
36-37	3	0.112	15.72	1.281	62.56	56.6	5.49	0.25	0.23	-27.18	6.59	12:1
40-41	3	0.157	17.31	1.414	68.7	62.6	5.55	0.33	0.23	-26.94	7.79	11:1

Results for STN 5

Depth (cm)	Unit	P (%)	C (%)	N (%)	CEC (me/100g)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
3-4	4	0.05	1.32	0.055	4.36	3.17	0.43	0.13	0.63	-24.78	4.99	19:1
7-8	4	0.053	0.75	0.089	3.83	3.2	0.44	0.1	0.1	-27.45	7.12	16:1
11-12	4	0.032	0.72	0.082	2.15	1.77	0.29	0.07	0.03	-26.81	8.35	15:1
15-16	3	0.132	11.58	1.793	36.76	33.47	2.65	0.38	0.25	-26.92	8.29	13:1
19-20	3	0.114	18.77	1.547	51.75	46.97	4.32	0.25	0.21	-27.14	8.91	12:1
23-24	3	0.107	12.95	1.035	39.11	35.47	3.11	0.27	0.25	-26.99	6.69	13:1
27-28	3	-	-	-	36.99	33.97	2.36	0.31	0.35	-	-	-
31-32	3	0.153	10.25	0.844	40.59	37.47	2.7	0.28	0.15	-26.92	7.12	12:1
35-36	3	0.178	23.91	1.567	64.18	59.47	4.11	0.39	0.2	-26.71	3.42	16:1
39-40	3	0.161	9.38	0.793	31.36	27.97	3.03	0.26	0.1	-26.92	7.1	13:1
43-44	3	0.156	16.76	1.477	55.52	48.47	6.55	0.33	0.17	-27.11	8.03	13:1
47-48	3	0.146	13.83	1.169	53.6	45.97	7.18	0.32	0.13	-26.88	8.7	13:1
51-52	3	0.243	13.02	1.118	43.4	38.47	4.45	0.36	0.12	-26.79	6.58	12:1
55-56	3	0.165	12.07	1.016	43.48	38.47	4.45	0.32	0.24	-26.86	8.22	12:1
59-60	3	0.2	10.22	0.954	46.1	41.47	4.03	0.33	0.27	-27.17	8.45	14:1
63-64	3	0.17	10.13	0.934	48.5	43.97	4.07	0.32	0.14	-26.72	7.28	11:1
67-68	3	0.181	8.89	0.733	34.44	30.97	3.2	0.22	0.06	-26.76	6.49	11:1
71-72	2	0.066	1.13	0.083	18.07	15.97	1.95	0.12	0.03	-25.98	5.75	15:1
75-76	2	0.071	1.7	0.159	8.66	7.6	0.86	0.11	0.09	-25.96	6.47	11:1

Results for STN 6

Depth (cm)	Unit	P (%)	C (%)	N (%)	CEC (me/100g)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
0-1	4	0.041	0.75	0.051	2.45	1.4	0.2	0.14	0.71	-26.03	6.85	15:1
4-5	4	0.042	1.11	0.092	4.17	3.42	0.43	0.06	0.26	-26.53	9.16	13:1
8-9	3	0.145	19.58	1.522	59.71	53.47	5.72	0.26	0.27	-26.92	8.14	12:1
12-13	3	0.206	14.5	1.3	65.13	57.97	6.65	0.22	0.28	-26.81	9.08	11:1
16-17	3	0.15	13.81	1.164	49.48	43.97	5.2	0.2	0.11	-26.86	8.38	12:1
20-21	3	0.163	11.57	1.027	46.61	39.47	5.51	0.39	0.24	-26.63	7.78	12:1
24-25	3	0.063	1.02	0.095	6.23	5.1	0.99	0.13	0.02	-26.19	8.46	14:1
28-29	2	0.067	5.7	0.278	26.28	23.47	2.57	0.15	0.09	-26.69	6.2	22:1
32-33	2	0.095	2.06	0.15	18.51	16.47	1.78	0.16	0.1	-26.82	6.72	22:1
36-37	2	0.091	1.63	0.098	9.5	8.22	1.11	0.12	0.04	-26.67	6.18	20:1
40-41	2	0.08	1.14	0.093	15.59	13.47	1.7	0.17	0.25	-25.96	5.96	14:1
44-45	2	0.115	4.17	0.369	8.29	7.1	1.03	0.12	0.05	-25.94	6.92	13:1

Results for STN 8

Depth (cm)	Unit	P (%)	C (%)	N (%)	CEC (me/100g)	Ca (me/100g)	Mg (me/100g)	K (me/100g)	Na (me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
1-2	4	0.047	2.96	0.249	14.8	13.47	1.03	0.13	0.17	-26.17	8.31	14:1
5-6	3	0.078	9.56	0.971	42.61	38.97	3.2	0.35	0.09	-26.4	9.66	11:1
9-10	3	0.101	9.64	0.779	38.66	35.47	2.74	0.34	0.11	-26.25	11.1	12:1
13-14	2	0.077	4.52	0.23	17.44	15.97	1.11	0.18	0.17	-26.63	16.54	21:1

Iceland

Results for CEGC Core 1

Depth (cm)	P (%)	N (%)	C (%)	CEC (Me/100g)	Ca (Me/100g)	Mg (Me/100g)	K (Me/100g)	Na (Me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
0-5	0.108	1.149	26.7	17.32	9.71	4.78	1.78	1.05	-28.8	0.84	22:1
5-10	0.146	1.444	27.53	16.07	8.34	5.2	1.41	1.12	-28.8	1.17	19:1
10-15	0.156	1.473	25.48	15.76	10.46	3.82	0.88	0.6	-28.6	1.3	17:1
15-20	0.168	1.524	22.17	17.72	12.46	3.95	0.78	0.53	-28.6	1.38	14:1
20-25	0.161	1.875	28.14	22.41	14.96	5.93	0.62	0.9	-28.8	1.94	19:1
25-30	0.154	1.822	28.78	18.97	13.21	4.36	0.57	0.83	-29.3	1.8	16:1
30-35	0.135	1.749	27.22	26.07	17.46	7.07	0.51	1.03	-29.3	3.15	16:1

Results for CEGC Core 2

Depth (cm)	P (%)	N (%)	C (%)	CEC (Me/100g)	Ca (Me/100g)	Mg (Me/100g)	K (Me/100g)	Na (Me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
0-5	0.151	1.102	19.99	16.36	10.09	4.2	1.14	0.93	-28.6	2.67	17:1
5-10	0.18	1.083	16.43	11.49	8.43	2.58	0.05	0.43	-28.5	3.02	15:1
10-15	0.17	0.858	11.38	9.41	6.59	1.78	0.22	0.82	-28.3	3.04	14:1
15-20	0.193	1.389	19.39	12.14	8.21	3.11	0.19	0.63	-29.1	3.53	14:1
20-25	0.201	0.948	13.74	10.85	8.09	2.2	0.07	0.49	-28.6	3.42	14:1
25-30	0.173	0.628	8.267	12.8	9.71	2.49	0.03	0.57	-27.5	1.2	15:1
30-35	0.184	0.711	9.845	12.8	9.59	2.57	0.04	0.6	-27.5	0.11	14:1
35-40	0.178	0.745	10.68	12.53	9.59	2.36	0.05	0.53	-27.7	-1.03	15:1
40-45	0.215	0.763	10.18	13.16	9.96	2.61	0.06	0.53	-27.5	1.05	15:1
45-50	0.181	0.445	5.588	9.12	6.93	1.75	0.04	0.4	-27.1	0.77	14:1
50-55	0.183	1.014	15.61	12.61	9.46	2.2	0.33	0.62	-28.5	3.33	16:1
55-60	0.221	1.553	22.17	13.51	9.09	3.15	0.26	1.01	-29.2	3.26	14:1
60-65	0.205	0.892	12.77	12.87	9.71	2.61	0.06	0.49	-28.3	2.69	15:1
65-70	0.178	0.641	8.629	14.77	10.84	2.95	0.08	0.9	-27.3	-0.07	14:1
70-75	0.191	0.799	10.9	15.01	11.21	3.11	0.05	0.64	-27.4	0.48	14:1
75-80	0.209	0.936	12.8	14.14	10.59	2.95	0.05	0.55	-27.6	0.28	15:1
80-85	0.218	0.672	9.002	9.58	7.09	1.95	0.09	0.45	-27.2	1.67	14:1
85-90	0.15	0.374	4.994	7.55	5.06	1.83	0.17	0.49	-26.8	3.59	15:1
90-95	0.099	0.156	1.571	7.39	4.93	1.21	0.59	0.66	-26.4	4.18	12:1

Results for CEGC Core 3

Depth (cm)	P (%)	N (%)	C (%)	CEC (Me/100g)	Ca (Me/100g)	Mg (Me/100g)	K (Me/100g)	Na (Me/100g)	$\delta^{13}C$ (‰)	$\delta^{15}N$ (‰)	C:N ratio
0-5	0.25	1.078	13.83	16.64	9.56	5.17	0.93	0.98	-28	5.29	14:1
5-10	0.301	0.997	12.2	10.24	5.56	3.79	0.32	0.57	-27.6	5.37	13:1
10-15	0.345	0.789	9.752	7.65	4.68	2.38	0.1	0.49	-27.5	6.02	13:1
15-20	0.535	0.753	8.084	7.98	4.93	2.46	0.09	0.5	-27.3	6.82	11:1
20-25	0.512	0.679	7.09	10.08	6.81	2.63	0.05	0.59	-27.2	6.13	11:1
25-30	0.331	0.715	7.578	14	9.68	3.75	0.05	0.52	-26.8	5.93	12:1
30-35	0.291	0.67	7.579	16.96	12.43	3.88	0.08	0.57	-26.9	5.01	12:1
40-45	0.325	0.697	8.053	19.75	15.06	4.08	0.05	0.56	-26.6	5.06	12:1
45-50	0.495	0.649	7.167	15.13	10.81	3.67	0.06	0.59	-	-	11:1
50-55	0.354	0.728	8.831	12.57	8.68	3.29	0.06	0.54	-27.1	6.13	12:1
55-60	0.327	0.713	8.097	13.88	9.43	3.71	0.07	0.67	-27.1	6.08	12:1
60-65	0.29	0.554	6.787	14.26	10.18	3.46	0.07	0.55	-26.6	6.35	12:1